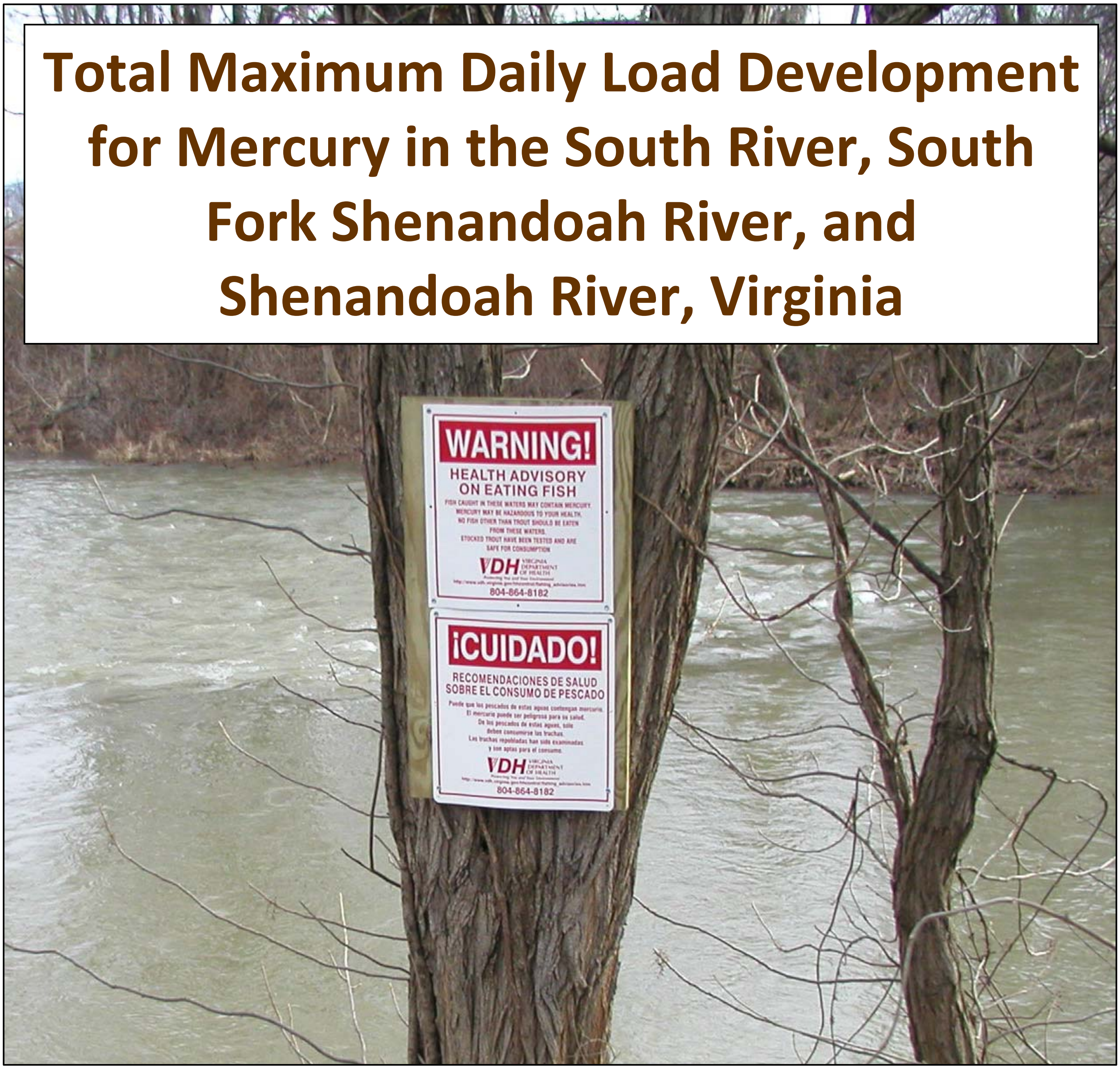
Total Maximum Daily Load Development for Mercury in the South River, South Fork Shenandoah River, and Shenandoah River, Virginia



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1. EXECUTIVE SUMMARY

Note: This executive summary is written in a "plain language" style to be easily understood by the general public. Technical details are contained in later sections of this report and Attachment 1.

1.1. BACKGROUND

In 1929, DuPont began making rayon fibers at a manufacturing plant in Waynesboro, Virginia. To help make these fibers, DuPont used a chemical that contained mercury. While DuPont recycled and reused most of the mercury, some of it went into the South River. Mercury was used at the plant from 1929 to 1950, so small losses added up to a lot of mercury over the 21 years. While it is impossible to know exactly how much mercury went into the river, a study in the 1980s roughly estimated around 100,000 pounds of mercury in the river and flood plain. At the time, the discharge of mercury was not illegal, and no one realized that mercury was potentially harmful. Today, we know that over exposure to mercury can cause brain, nerve, and kidney problems, especially in children.

Once discharged into the South River from the DuPont plant, mercury contamination was spread downstream for over 150 miles. This includes 25 miles of the South River (from the DuPont plant downstream to Port Republic, Virginia), 100 miles of the South Fork Shenandoah River (from Port Republic to Front Royal, Virginia), and 30 miles of the Shenandoah River (to nearly the West Virginia state line). Even though mercury use at the DuPont plant stopped more than 50 years ago, fish in these rivers still contain more mercury that what is considered safe to eat.

1.2. THE PROBLEM – TOO MUCH MERCURY IN THE FISH

To make sure that fish are safe to eat, the Virginia Department of Health (VDH) sets limits on the amount of mercury allowed in fish from Virginia's lakes and rivers. If fish have more than 0.5 parts per million (ppm) of methylmercury (the predominant form of mercury found in fish), VDH warns people against eating fish from that river or lake. The U.S. Environmental Protection Agency (USEPA) recommends an even lower level of 0.3 ppm as safe. Fish from the

South River, South Fork Shenandoah River, and Shenandoah River are above this safe level of 0.3 ppm methylmercury (Figure 1-1).

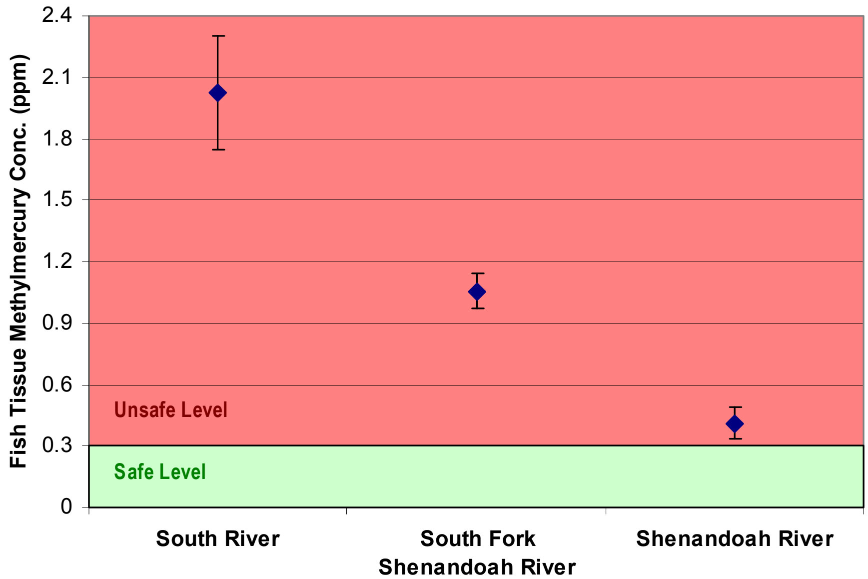


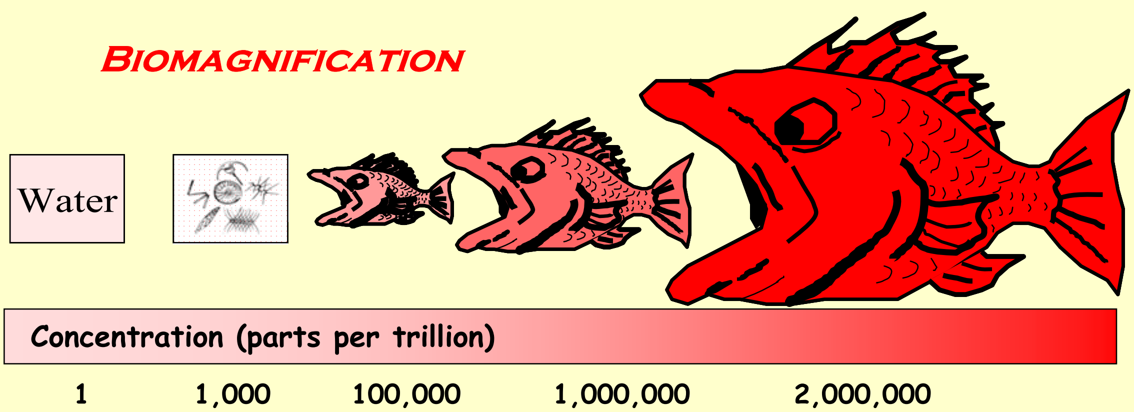
Figure 1-1. Levels of Methylmercury in Smallmouth Bass in 2007.

Based on the amount of methylmercury in fish from these rivers, VDH warns people not to eat fish from the South River and not to eat more than 2 meals per month of fish from the South Fork Shenandoah and mainstem Shenandoah Rivers. Pregnant women and children are warned not to eat any fish from these rivers. In addition, people should not eat carp, catfish, or suckers in the Shenandoah River and lower portions of the South Fork Shenandoah due to another pollutant (polychlorinated biphenyls or PCBs from the former Avtex facility in Front Royal, Virginia).

Unsafe levels of methylmercury in fish have also caused these rivers to be placed on Virginia's "Dirty Waters List" (or 303(d) list). These rivers were first placed on this list in 1998. Rivers placed on the list must have clean-up plans, and this report is the first step in developing a clean-up plan for mercury in the South, South Fork Shenandoah, and Shenandoah Rivers. This report summarizes a study of mercury in these rivers and sets goals for the clean-up plan. The study is called a Total Maximum Daily Load (TMDL) Study, because it determines the maximum amount of mercury that can get into each river without producing fish that are unsafe to eat.

Why Are Fish a Problem?

Certain bacteria are able to transform mercury into methylmercury, a form of mercury that has the ability to **biomagnify** in aquatic food chains. This means that the concentration of methylmercury generally increases with each step in the food chain. For instance, algae may accumulate 1000 times more methylmercury than the water around it. When aquatic insects eat that algae they may accumulate 100 times more than what was in the algae. A small fish eating that insect may accumulate 10 times more methylmercury. A large fish that eats the smaller fish may accumulate twice as much methylmercury as the small fish. This increase at each link in the food chain means that large fish, like the ones fisherman are likely to catch and eat, may have millions of times more methylmercury than the water contains. This is why mercury contamination in a river results in advisories against eating certain fish.



1.3. SOURCES OF MERCURY

The original source of most of the mercury in the South River was from the DuPont plant site, but because that mercury has been spread throughout the flood plain, the current sources are much broader. A small amount of mercury also comes from natural sources or from atmospheric deposition. All of the different mercury sources identified in the study are described below:

- Point Sources – A total of 14 businesses and towns are permitted to discharge treated wastewater into the South River. This study measured the amount of mercury in all three of the industrial discharges and the two largest municipal discharges. Overall, the amount of mercury from these sources was relatively small, but the former DuPont plant contributed the most. DuPont continues to own the property and leases the property to Invista, which owns and operates the manufacturing assets. Even though Invista does not currently use mercury in its operations, mercury continues to be released from contaminated soil and sediment in drainage pipes on the site. Under a federal program that directs clean up of contaminated sites (the Resource Conservation and Recovery Act), DuPont is actively trying to find and clean up these sources of mercury on the plant site.

- Atmospheric Deposition – A small amount of mercury can come from atmospheric deposition, or fallout from the air. Coal naturally contains some mercury, so when it is burned, the mercury is released into the air. That mercury can then fall back to the ground some distance away. Atmospheric deposition of mercury in the South River watershed was estimated from testing at air monitoring stations along the Blue Ridge Mountains.

- Runoff – Some mercury in the soil can make its way to the South River through runoff. When rainwater moves soil from the land to the stream, mercury that is attached to that soil gets moved too. Runoff can carry mercury that is naturally occurring in the soil, mercury that has fallen onto the soil from atmospheric deposition, or mercury from the DuPont plant that has contaminated the river flood plain. The majority of mercury in runoff is from erosion of the contaminated flood plain. Floods during the period that mercury was being used by DuPont deposited mercury on the flood plain, and it is slowly making its way back to the river through erosion and runoff.

- Groundwater – Mercury that is in groundwater can add to the amount of mercury in the South River. Mercury in groundwater can come from rainwater itself or from mercury in the soil that is picked up as rainwater drains through it. This study measured the amount of mercury in groundwater near the DuPont plant site and in the contaminated flood plain further downstream.

- Interflow – Interflow is a type of groundwater that discharges quickly after a rain. Interflow can carry mercury from the atmosphere or mercury that is picked up from the soils.

- Stream Banks – Mercury can also come from the banks of the river. Like the flood plain, the river banks downstream of the DuPont plant site have much higher levels of mercury than banks upstream of the plant site. Erosion of those banks can add mercury to the river.

1.4. COMPUTER MODELING

The U.S. Geological Survey (USGS) used a computer model called the Hydrological Simulation Program – Fortran (or HSPF) to track mercury from its different sources, to the South River, and then downstream to the South Fork Shenandoah River. The amount of mercury that ends up in the river depends on a lot of different factors, including: the amount of mercury available from each source, the timing of inputs from those sources, how much and when it rains, how much runoff is generated, how the mercury binds with sediment in the river, and how sediment moves within the river. The model considered these and other factors to estimate the amount of mercury in the South River at any given time. To make sure that the estimates are accurate, the model was tested with real-world data. The model was used to estimate mercury levels in the South River from April 2005 to April 2007, and these estimates were compared to mercury samples collected from the river during that time period. Once the model was calibrated, or adjusted to successfully match the real-world data, it could be used to make predictions about how mercury levels in the South River might change if mercury sources were controlled.

> **Frequently Asked Question:**
>
> *Why use a computer model?*
> Sampling and testing tells you a lot about the present and the past, but nothing about the future. A computer model is a tool that can help you make predictions about the future. This is necessary to figure out how much effort is needed to clean up a stream.

1.5. CURRENT CONDITIONS

The USGS used the computer model to figure out where the mercury in the South River was currently coming from. Figure 1-2 shows that the majority of the mercury in the South River (84%) comes from the banks (or channel margins). A smaller portion (15%) comes from runoff. Most of that mercury in runoff is from mercury in the contaminated flood plain that runs off with sediment. The remaining sources, which include groundwater, atmospheric deposition, and point sources, add up to only about 1% of the total amount of mercury that enters the South River. The percentages given in Figure 1-2 represent mercury loads to the whole South River during an average year. Of course on any given day, the amount of mercury coming from each source could be very different from these percentages. For instance, the contribution from point sources and groundwater would be much greater during dry periods when there is no runoff and very little bank erosion. Throughout an average year, though, the amount of mercury coming from banks and runoff swamp all other sources of mercury.

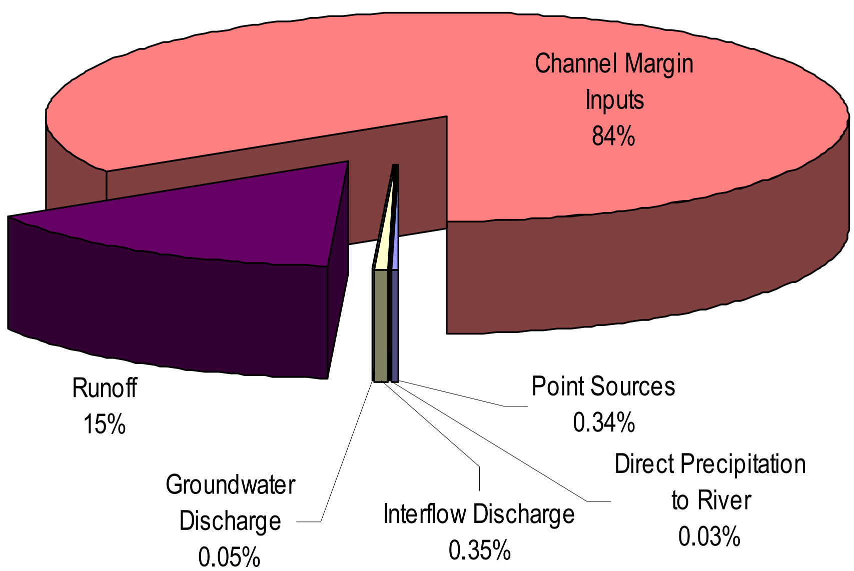


Figure 1-2. Where is the Mercury Currently Coming From?

1.6. FUTURE GOALS (THE TMDL)

After figuring out where mercury in the South River is currently coming from, the computer model was used to figure out how much mercury loads need to be reduced to clean up the South River. The ultimate goal is for people to be able to safely eat fish from the South River, South Fork Shenandoah, and Shenandoah Rivers. To do this, there will need to be an overall 99% reduction in the amount of mercury entering the South River. This goal can be achieved by reducing atmospheric and interflow inputs by 19%, reducing point source inputs by 83%, reducing runoff loads by 96%, and eliminating channel margin loads (Table 1-1). If these reductions were made, less than 2,029 grams of mercury per year would enter the South River. This safe amount, known as the total maximum daily load (TMDL), is the maximum amount of mercury that can enter the South River and still produce fish that are safe to eat. A small portion of this amount (112 g per year) is reserved for the permitted sewage and industrial treatment plants in the area (point sources), but most of the amount allows for mercury coming from the air and land surface (nonpoint sources) (Table 1-2). The good news is that if these reductions are made in the South River, no additional mercury reductions will be needed in the South Fork Shenandoah or Shenandoah Rivers. Fish in these rivers should be safe to eat if the necessary reductions are made in the South River, where the mercury problem begins.

Definition:

TMDL – Total Maximum Daily Load. This is the amount of a pollutant that a stream can receive and still meet water quality standards. The term TMDL is also used more generally to describe the state's formal process for cleaning up polluted streams.

TMDL = WLA+LA+MOS
where,
WLA = wasteload allocation
LA = Load allocation
MOS = Margin of safety

Table 1-1. Reductions in Mercury Sources Needed to Clean Up the South River.

Source	Mercury Reductions Necessary to Produce Fish that are Safe to Eat	Mercury Load After Reductions (g/yr)	Explanation of Reductions
Precipitation directly to the river	19%	45	Should be met through new air permitting rules
Interflow discharge	19%	558	
Groundwater discharge	0%	99	Reductions in groundwater are difficult to implement so none are called for
Runoff	96%	1,216	A 96% reduction is the same as returning flood plain soils to background levels
Channel margin inputs	100%	0	Elimination of virtually all of the mercury from the banks will be needed
Point sources	83%	112	An 83% reduction means point sources discharge less than 3.8 ng/L of mercury
Total	99%	2,029	

The necessary mercury reductions in the South River are very large (99%) and will be difficult to achieve by simply controlling sources of mercury to the South River. Complete restoration of an edible fishery may require innovative approaches that bind or remove mercury in the river or slow the process by which mercury is brought into and moved through the food chain.

Table 1-2. Total Maximum Daily Loads of Mercury in the South River, South Fork Shenandoah River, and Shenandoah River that Will Meet Water Quality Standards.

Stream	Amount from Permitted Point Sources (WLA) (g/yr)	Amount from Nonpoint Sources (LA) (g/yr)	Margin of Safety	Total Maximum Daily Load (g/yr)
South River	112	1917	Implicit	2029
South Fork Shenandoah River	112	4008	Implicit	4120
Shenandoah River	112	5948	Implicit	6060

1.7. WHAT HAPPENS NEXT

The Virginia Department of Environmental Quality (VADEQ) will ask for public comment on this report and then submit it to the USEPA for approval. This report sets the clean-up goal for the South River, but the next step is a clean-up plan (or Implementation Plan) that lays out how that goal will be reached. The clean-up plan will set intermediate goals and describe actions that should be taken to clean up the South River. Some of the possible actions are listed below:

- Finding and removing mercury on the plant site
- Reducing mercury in point source discharges
- Stabilizing or restoring eroding stream banks
- Decreasing runoff of mercury contaminated soil from the flood plain
- Finding and removing (or immobilizing) hot spots of mercury contamination in sediments, banks, or the flood plain
- Discovering ways to reduce the amount of mercury that gets into the food chain

Interesting Fact:

The TMDL for South River is 2029 grams of mercury per year. This is about as much mercury as in 1,000 thermometers.

The clean-up plan will evaluate these and other options for reducing mercury in fish. The plan will consider the level of effort and the associated costs with each potential action and will select a set of reduction strategies that most efficiently restore the fishery. The clean-up plan will also identify potential sources of money to help in the clean-up efforts.

VADEQ will continue to sample fish in the South River, South Fork Shenandoah, and Shenandoah Rivers to monitor the progress of clean-up. This sampling will let us know when the clean-up has reached certain milestones listed in the plan. The ultimate milestone is for fish in these rivers to be safe to eat. When we reach that point, fish consumption advisories on the rivers can be removed.

2. INTRODUCTION

2.1. WATERSHED LOCATION AND DESCRIPTION

The South River is located primarily in Augusta County, Virginia (Figure 2-1). The South River is 50.8 miles in length and flows north from its headwaters in southern Augusta County, through the City of Waynesboro, and into Rockingham County. In Port Republic, Virginia, the South River joins with the North River to form the South Fork of the Shenandoah River. The drainage area of the South River is 235 square miles (607 km^2), with 89% in Augusta County, 6% in the City of Waynesboro, and 5% in Rockingham County.

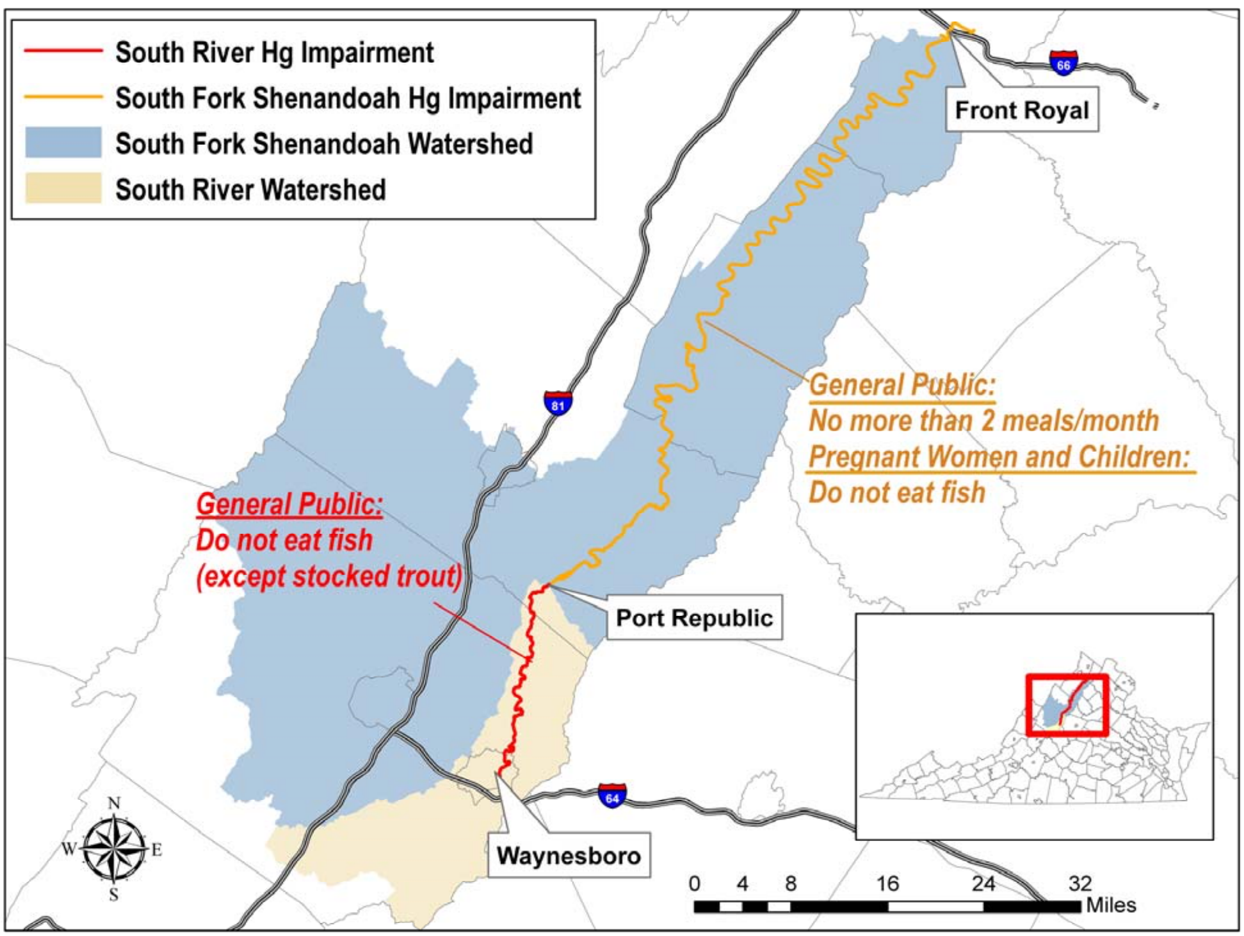


Figure 2-1. Fish Consumption Advisories for Mercury in the South River and South Fork Shenandoah River.

The South Fork Shenandoah River is located in Rockingham, Page, and Warren Counties, Virginia. The South Fork Shenandoah River is approximately 100 miles in length and flows north from Port Republic, Virginia, to Front Royal, Virginia, where it joins with the North Fork of the Shenandoah to form the Shenandoah River. The Shenandoah River drains to the Potomac River, which ultimately flows to the Chesapeake Bay. The South Fork Shenandoah River drains approximately 1,700 square miles (4,500 km^2). The South River contributes 14% of this drainage area, the North River contributes 48%, and 38% drains directly to the South Fork Shenandoah River. Land use within the South Fork Shenandoah watershed is mostly forested (58%), with 38% in agriculture and only 4% in residential and urban uses (VADCR, 2008).

2.2. BACKGROUND

Since 1977, the South River and South Fork Shenandoah River have been posted with fish consumption advisories due to mercury contamination. Currently, VDH advises no consumption of wild fish from the South River downstream of the DuPont footbridge in Waynesboro and no more than two meals per month for fish from the South Fork Shenandoah River (Figure 2-1). Pregnant women and children are advised to eat no wild fish from the South River or South Fork Shenandoah River. Due to fish movement, small sections of the North Fork Shenandoah River and mainstem Shenandoah River are listed with the same advisory as the South Fork Shenandoah River. This applies to the North Fork Shenandoah River from the confluence with the South Fork upstream to the Riverton Dam and the mainstem Shenandoah River from the confluence with the South Fork downstream to the Warren Power Dam.

Mercury contamination in the South River originally resulted from historic releases from a DuPont manufacturing facility in Waynesboro, Virginia. Between 1929 and 1950, DuPont used a mercuric sulfate catalyst in the manufacturing of acetate fibers. While the majority of the mercury catalyst was captured and reused, losses from the facility to the river over the 21 years of use resulted in widespread mercury contamination downstream (SWCB, 1980). A 1989 study provided a rough estimate of 1,800 pounds of mercury in downstream river sediments and 97,200 pounds of mercury in flood plain soils (Lawler, Matusky & Skelly Engineers, 1989). While initial studies indicated that fish mercury concentrations would slowly decrease without any remedial action (Lawler, Matusky & Skelly Engineers, 1982), no discernable declines in fish tissue levels have been observed in the 30 years since mercury contamination in the river was first discovered.

Results from the most recent fish sampling in 2007 showed that the current fish consumption advisories are warranted. Above the DuPont footbridge in Waynesboro, methylmercury in fish fillets averaged <0.3 ppm for all fish species. At monitoring sites below the DuPont footbridge, methylmercury levels in smallmouth bass averaged from 0.644 to 3.107 ppm, white suckers averaged from 0.36 to 2.366 ppm, and redbreast sunfish averaged from 1.038 to 2.147 ppm (VADEQ, 2008a). Stocked rainbow trout were all well below 0.3 ppm. Along the length of the South Fork Shenandoah, methylmercury levels in smallmouth bass averaged from 0.733 to 1.326 ppm, white suckers averaged 0.383 to 0.781 ppm, redbreast sunfish averaged 0.456 to 0.644 ppm, channel catfish averaged 0.761 to 0.878 ppm, and northern hogsuckers averaged 0.305 to 0.483 ppm.

In 1998, USEPA issued a Resource Conservation and Recovery Act (RCRA) permit to DuPont for investigation and clean up of residual mercury contamination on the plant site. DuPont is currently in the process of conducting a RCRA facility investigation at the site. This activity has involved groundwater, stormwater, and soil testing on the plant site. After completing the investigation, corrective actions will be taken to address solid waste management units that pose a human health or ecological risk. This effort by DuPont will be integral to reducing or eliminating mercury discharges from the site. In addition, DuPont has been investigating mercury contamination in the South River ecosystem as part of a settlement agreement with the Natural Resources Defense Council and the Sierra Club. This six-year study includes a first phase that characterizes mercury impacts in the South River ecosystem and a second phase that focuses on specific sources of mercury and mercury methylation sites. Results from these and other South River studies are periodically presented to the South River Science Team, a collection of state and federal agencies, stakeholders, and researchers interested in South River mercury issues.

In 2004, DuPont sold the manufacturing assets of the Waynesboro plant to subsidiaries of Koch Industries, Inc., and the name of the facility was changed to Invista. DuPont continues to own the property and retains responsibility for environmental clean up under the RCRA permit.

Invista now owns and operates the manufacturing assets, including the stormwater and wastewater outfalls permitted by VADEQ.

2.3. IMPAIRMENT LISTING

Based on the continuing fish consumption advisory on the South River and South Fork Shenandoah River, VADEQ placed these rivers on the 1998 303(d) Impaired Waters List (VADEQ, 1998). The 1998 listing included only 103.4 miles of river, including the South River downstream from the DuPont footbridge and the South Fork Shenandoah River downstream to the Page/Warren County line. Since that original listing, the impairment listing has expanded based on additional monitoring, consideration of fish movement, and changes in the fish tissue methylmercury criterion.

The current fish consumption impairment listing for mercury includes 156.09 miles of river (VADEQ, 2008b). This includes the South River from the Invista (formerly DuPont) discharge to the confluence with the North River, the full length of the South Fork Shenandoah River, a short section of the North Fork Shenandoah River upstream to the Riverton Dam, and the mainstem Shenandoah River to its confluence with Craig Run (Table 2-1). The current impairment listing includes an additional 26 miles on the mainstem Shenandoah River, which extends further downstream than the existing fish consumption advisory. This segment was added to the impaired length in the 2008 assessment due to additional fish tissue monitoring further downstream. The fish consumption advisory has not been lengthened to include this portion for mercury, because this segment already contains a more restrictive fish consumption advisory for PCBs originating from the former Avtex facility in Front Royal, Virginia (do not eat carp, channel catfish, and sucker species; no more than 2 meals/month for bass and sunfish species).

Table 2-1. Fish Consumption Impairment Listing for Mercury.

River	Upstream Extent	Downstream Extent	Stream Miles
South River	Invista Discharge	Confluence with North River	24.63
South Fork Shenandoah River	Confluence of South River and North River	Confluence with NF Shenandoah	100.96
North Fork Shenandoah River	Riverton Dam	Confluence with SF Shenandoah	0.67
Shenandoah River	Confluence of North Fork and South Fork Shenandoah	Confluence with Craig Run	29.83
		Total	**156.09**

2.4. DESIGNATED USES AND APPLICABLE WATER QUALITY STANDARDS

Virginia's Water Quality Standards (9 VAC 25-260) consist of designated uses established for water bodies in the Commonwealth, and water quality criteria set to protect those uses. Virginia's Water Quality Standards protect the public and environmental health of the Commonwealth and serve the purposes of the State Water Control Law (§62.1-44.2 *et seq.* of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 *et seq*.).

2.4.1. Designation of Uses (9 VAC 25-260-10)

Virginia's Water Quality Standards (9 VAC 25-260) establish the following designated uses:

> *"A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish"* (SWCB, 2006).

The above listed uses are designated for all state waters, including the South River, South Fork Shenandoah, and Shenandoah Rivers. These rivers do not support the fish consumption designated use (i.e., production of edible and marketable natural resources) due to the mercury contamination and resulting fish consumption advisories.

2.4.2. Applicable Water Quality Criterion for Mercury

Virginia's current mercury criterion for the protection of human health from fish consumption is a water column total mercury concentration of 0.051 ug/L (9 VAC 25-260-140). This criterion was developed based on the methodology provided in the 1980 *Ambient Water Quality Criteria for Mercury* (USEPA, 1980). Using this methodology, Virginia calculated the criterion according to the following equation and values.

$$WQC = \frac{RfD \times BW}{FI \times PBCF} \qquad [2\text{-}1]$$

Where,

WQC = Water Quality Criterion (0.051 ug/L),
RfD = Reference Dose (0.1 ug/kg/d),
BW = Body Weight (70 kg),
FI = Fish Ingestion Rate (0.0187 kg/d), and
$PBCF$ = Practical Bioconcentration Factor (7342.6 L/kg).

While this methodology and these assumed values were appropriate at the time, advancements in the scientific understanding of methylmercury bioaccumulation and health effects have led to new methodologies and assumptions for developing more protective water quality criteria for mercury. In response, USEPA published the *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health* in 2000 (USEPA, 2000) and *Water Quality Criterion for the Protection of Human Health: Methylmercury* in 2001 (USEPA, 2001). In the 2001 Methylmercury Criterion Document, USEPA established a new fish tissue residue criterion of 0.3 ppm methylmercury in fish tissue using the following equation and assumptions:

$$TRC = \frac{BW \times (RfD - RSC)}{FI} \qquad [2\text{-}2]$$

Where,

TRC = Fish tissue residue criterion (0.3 ppm methylmercury in fish tissue),
BW = Human body weight (70 kg),
RfD = Reference dose (0.0001 mg/kg),
RSC = Relative source contribution (2.7×10^{-5} mg/kg), and
FI = Fish intake rate (0.0175 kg/d).

This fish tissue residue criterion replaces the ambient water quality criterion for total mercury published in 1980. This new criterion also represents a significant change in methodology by being expressed in terms of a fish tissue residue rather than a water column concentration. USEPA's *Draft Guidance for Implementing the January 2001 Methylmercury Water Quality Criterion* (USEPA, 2006) explains that, among other reasons, this approach is preferred because it avoids the need for assuming standard bioaccumulation factors (BAFs), which are highly site-specific. When TMDLs or NPDES (National Pollutant Discharge Elimination System) permits necessitate the establishment of a water concentration-based criterion, USEPA recommends using a site-specific bioaccumulation factor or bioaccumulation model to translate the 0.3 ppm fish tissue criterion.

In response to USEPA's updated water quality criterion for mercury, the Commonwealth of Virginia has proposed to revise the State Water Quality Standards to adopt the new 0.3 ppm criterion for methylmercury (SWCB, 2008). This revision to the Water Quality Standards was proposed on March 31, 2008, and public comment was accepted from March 31 to May 30, 2008. Final adoption of the new methylmercury criterion is expected in 2009.

Based on USEPA's recommended water quality criterion for methylmercury and Virginia's proposed water quality standards revision, **the applicable water quality criterion for this TMDL was determined to be a fish tissue methylmercury concentration of 0.3 ppm**. This criterion was then translated to a protective water quality target using a site-specific empirical bioaccumulation model.

It should be noted that background methylmercury concentrations in fish that are upstream from the mercury contaminated area are just below this threshold. Methylmercury concentrations in size-normalized smallmouth bass at the upstream reference site average 0.29 ppm. This indicates that restoration of the fish consumption designated use will require reductions in mercury loadings to near background levels.

2.4.3. Development of a Site-specific Water Quality Target

In order to develop a TMDL that links mercury loadings to the applicable fish tissue criterion, it is necessary to translate the fish tissue criterion to a protective water quality target concentration.

USEPA recommends several appropriate approaches that can be used to make this translation (USEPA, 2001). These approaches include using a mechanistic bioaccumulation model, an empirical bioaccumulation model, or a bioaccumulation factor. Each of these approaches has distinct advantages, disadvantages, and data requirements. Based on the data available for the South River, a site-specific empirical bioaccumulation model approach was used to translate the 0.3 ppm methylmercury fish tissue criterion to a protective water quality target concentration. The remainder of this section describes the rationale for selecting this approach and the details of developing the translator.

Mechanistic bioaccumulation models were initially considered for translating the fish tissue criterion. Mechanistic models are attractive because they directly represent many factors that may be important in mercury methylation and bioaccumulation. However, a limited number of such mechanistic models have been developed, and those that have been developed have not been applied to free-flowing rivers. In addition, the information necessary to properly parameterize a mechanistic model is not currently available for the South River. In consultation with the South River Science Team (SRST), it was determined that the present understanding of specific factors controlling mercury methylation and bioaccumulation in the South River was not sufficient to adequately support the development of a mechanistic bioaccumulation model.

The bioaccumulation factor approach was also considered for translating the fish tissue criterion in the South River. A bioaccumulation factor (BAF) is the ratio of mercury in fish tissue at the site to mercury in the water column. Using this approach, the fish tissue criterion can simply be divided by the BAF to obtain a protective water quality target concentration. The BAF approach has the advantage of considering site-specific bioaccumulation information without having to define and individually model those biotic and abiotic factors controlling bioaccumulation. The approach allows for more simplified modeling of total mercury loads. One of the disadvantages of the BAF approach is that it assumes a linear relationship between mercury in fish tissue and mercury concentrations in the water column, such that BAFs are independent of water column concentrations. Southworth *et al.* (2004) suggest that this assumption is unlikely, particularly at highly contaminated sites, such as the South River. Using data from 13 freshwater streams in Tennessee, Kentucky, North Carolina, and Virginia (including the South River and South Fork Shenandoah River), Southworth *et al.* demonstrated that BAFs were lower at contaminated sites than uncontaminated sites and tended to be lowest in the most contaminated systems. If BAFs indeed decrease with increasing mercury contamination levels, TMDLs based on BAFs calculated at contaminated sites will under predict the level of reductions needed to protect fish consumption uses. As reductions in total mercury loadings are made, BAFs will increase, and resulting reductions in fish contaminant levels will be less than anticipated.

To avoid this under prediction in the South River TMDL project, VADEQ decided to use a site-specific empirical bioaccumulation model that considers the non-linear relationship between mercury in fish tissue and mercury in the water column. The South River and South Fork Shenandoah River system contains approximately 130 miles of river that generally decreases in mercury contamination moving downstream away from the historical point source of mercury in Waynesboro. VADEQ collected water column and fish tissue mercury levels at numerous sites along the stretch of these rivers, and indeed BAFs decrease with increasing levels of mercury contamination. With collocated water column and fish tissue mercury levels that span the range of contamination, an empirical model of the non-linear water column to fish tissue mercury relationship could be developed and used to predict a water column target concentration that would be protective of the 0.3 ppm fish tissue criterion. The remainder of this section discusses the development of this site-specific empirical bioaccumulation model.

2.4.3.1. Data Collection

VADEQ collected water column and fish tissue mercury samples from ten stations along the South River and South Fork Shenandoah River (Figure 2-2). Fish and water column samples were either collected from the same location or in close proximity depending on river access for fish sampling gear and available fish habitat. At seven of these stations, VADEQ has conducted bimonthly water column sampling of mercury since 2002. The remaining three stations (1BSTH014.49, 1BSTH004.21, and 1BSSF100.10) were added to the bimonthly sampling schedule in 2004. Water column samples were collected by submerging a 4L plastic bottle to 1/3 of the stream depth in the mid channel. Ultra clean sampling techniques involving “clean hands/dirty hands” procedures were used according to VADEQ standard operating procedures for collection of trace elements (VADEQ, 2005). An aliquot of the collected sample was filtered in the field through a 0.45 µm filter for analysis of filter-passing mercury (procedurally defined as “dissolved” mercury). This sample and an unfiltered aliquot for total mercury analysis were packed on ice and shipped to the Division of Consolidated Laboratory Services for analysis. Total and filter-passing mercury were analyzed using USEPA Method 1631 (USEPA, 2002).

Fish data collected from 1999 through 2005 were used in the development of a site-specific water quality target. Fish were collected during the spring through fall with the use of backpack electroshocking equipment in wadeable stream sections or boat mounted electroshocking equipment in deeper stream segments. The sampling targeted smallmouth bass as representative predators, redbreast sunfish as representative grazers, and white suckers as representative bottom feeders. If the target organisms were not present at a specific sampling location, other available species within the predator, grazer, and bottom feeder functional groups were sampled. Up to nine fish per species within the edible size range were collected from each sampling location. Fish were weighed and measured in the field and packed on ice for transport to VADEQ. Samples were then frozen and shipped to the Division of Consolidated Laboratory Services for analysis. Skin-on fillets from each fish were analyzed for total mercury using USEPA Method 1631 (USEPA, 2002). Results from previous studies have shown that approximately 90% of total mercury in South River fish is in the form of methylmercury (VADEQ, 2008a), so measured total mercury concentrations were multiplied by 0.9 to obtain estimated methylmercury concentrations in fish tissue.

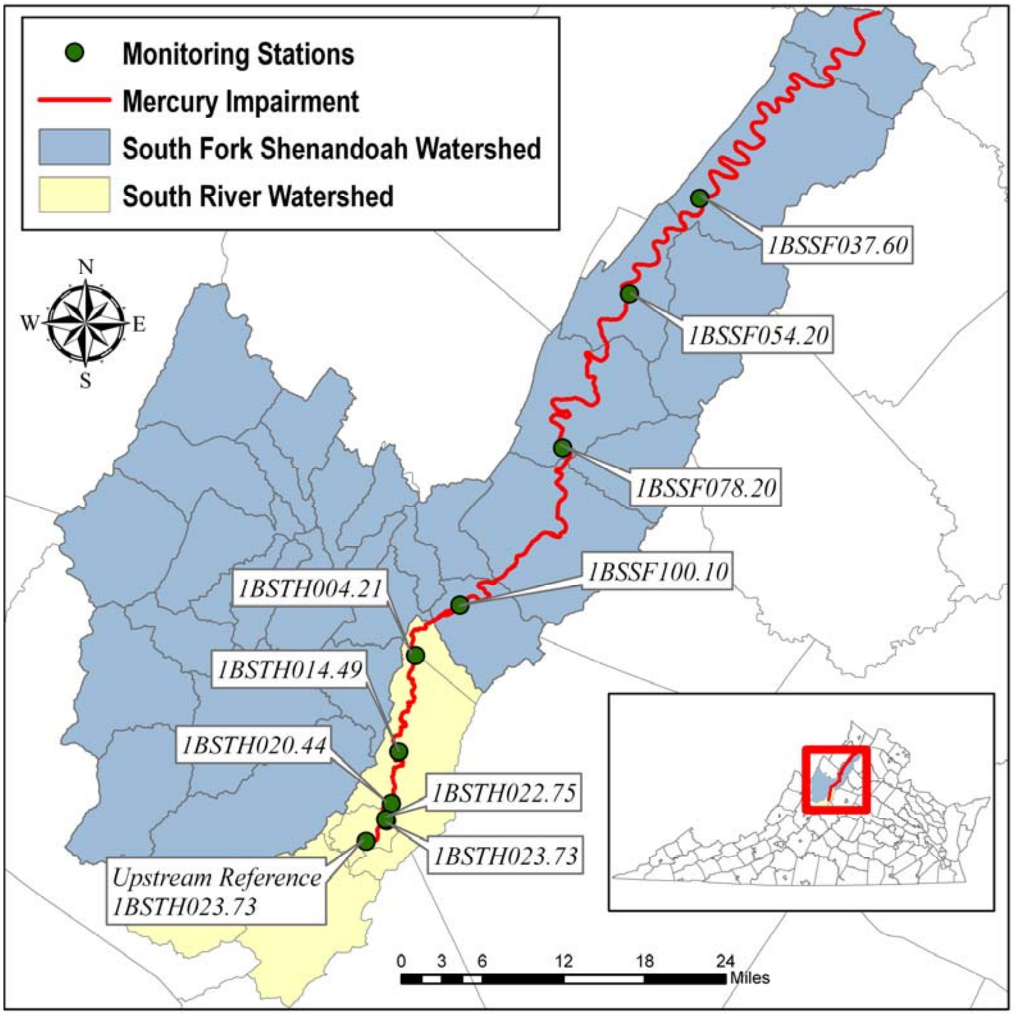


Figure 2-2. Collocated (or Proximally Located) Water Quality and Fish Tissue Sampling Stations.

2.4.3.2. Fish Tissue and Water Column Results

All fish species collected in the South River and South Fork Shenandoah River averaged above the applicable water quality criterion (0.3 ppm) with the exception of rainbow trout, which are hatchery raised and seasonally stocked in the South River (Figure 2-3). Being closer to the original source of mercury contamination, fish in the South River accumulated significantly more methylmercury than fish in the South Fork Shenandoah. In both rivers, the highest levels of methylmercury are accumulated in the piscivorus predators (largemouth bass and smallmouth bass), which fill the top trophic level in these river systems. To provide conservative estimates in the TMDL, methylmercury accumulation in these top trophic level predators were used to develop the protective water quality target concentration. Specifically, smallmouth bass were used as the target species, because smallmouth bass had the highest methylmercury levels (averaging 2.0 ppm), and these fish are the most often sought after species by anglers on these rivers.

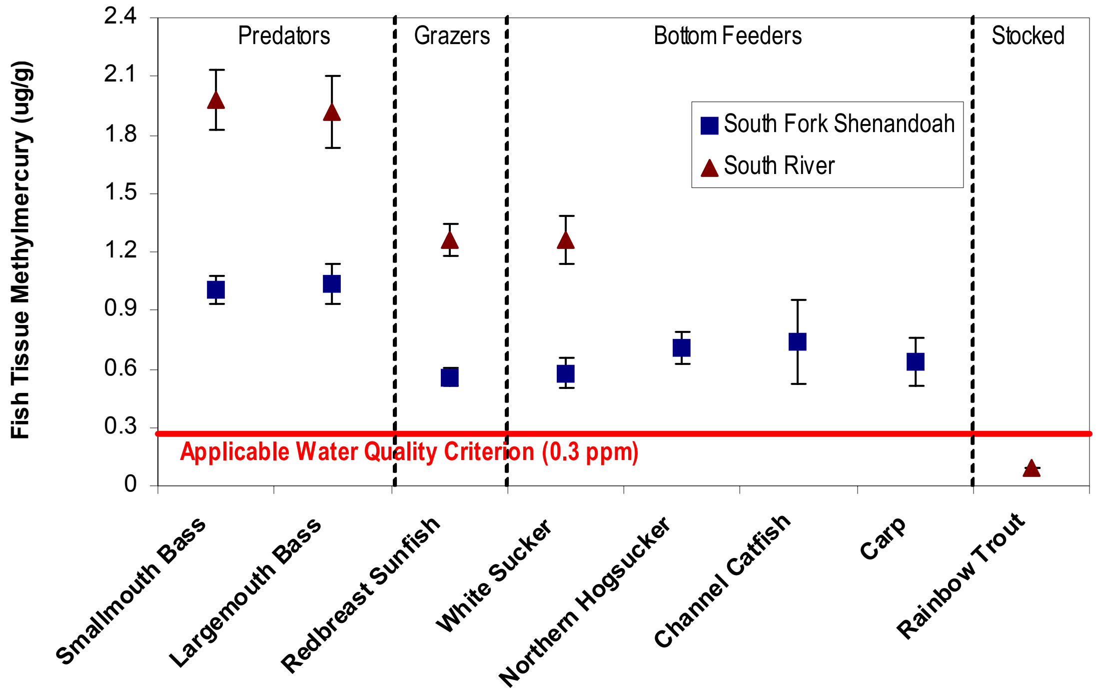


Figure 2-3. Average Methylmercury Concentration in Fish Tissue from Various Species in the South River and South Fork Shenandoah River.

In addition to varying by species, fish tissue methylmercury levels varied by fish size. Older, larger fish had higher body burdens of methylmercury than younger smaller fish (Figure 2-4). For this reason, fish methylmercury levels were normalized to a standard fish size in developing the protective water quality target concentration. This normalization was conducted by dividing the fish tissue methylmercury concentration of each fish by the weight of that fish, and then multiplying by a representative fish size. Separate water quality targets were developed for the South River, South Fork Shenandoah River, and Shenandoah River based on different representative fish sizes, since fish size increased with downstream increases in flow and available habitat. In each river, the size of smallmouth bass was lognormally distributed, so the representative size in each river was determined from the lognormal cumulative distribution function (Figure 2-5 through Figure 2-7). Based on the mean and standard deviation of natural log transformed data, the lognormal cumulative distribution function was used to identify the fish size in each river that would have a cumulative probability of 50%. This representative size fish was determined to be 218 g in the South River, 253 g in the South Fork Shenandoah River, and 321 g in the Shenandoah River.

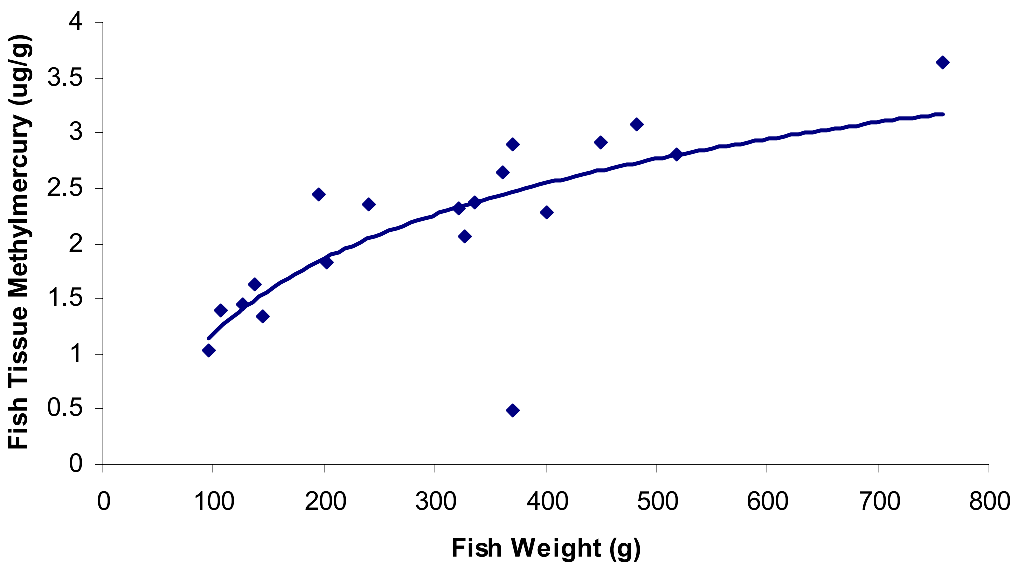


Figure 2-4. Influence of Fish Size on Methylmercury Accumulation; Smallmouth Bass from Station 1BSTH004.21.

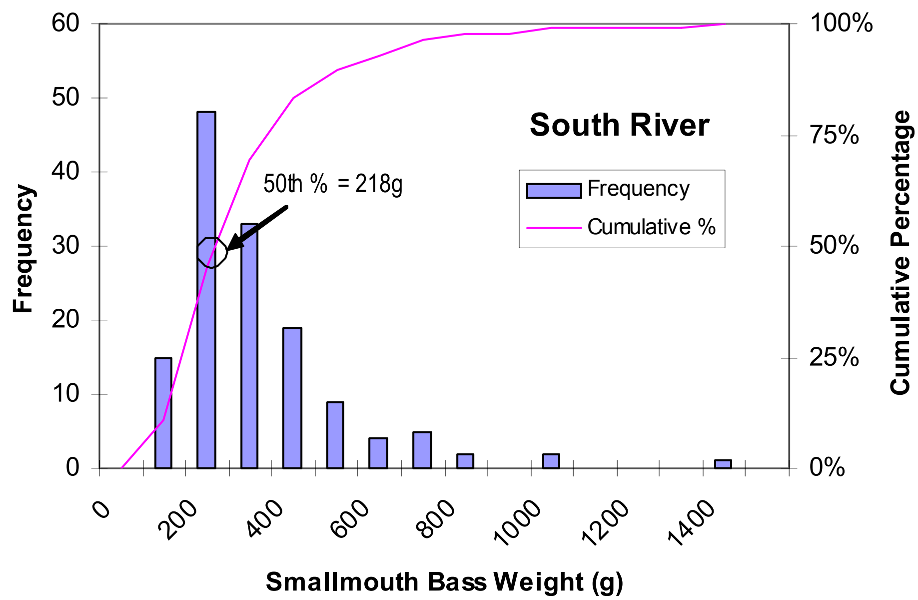


Figure 2-5. Histogram of Smallmouth Bass Size (g) in the South River.

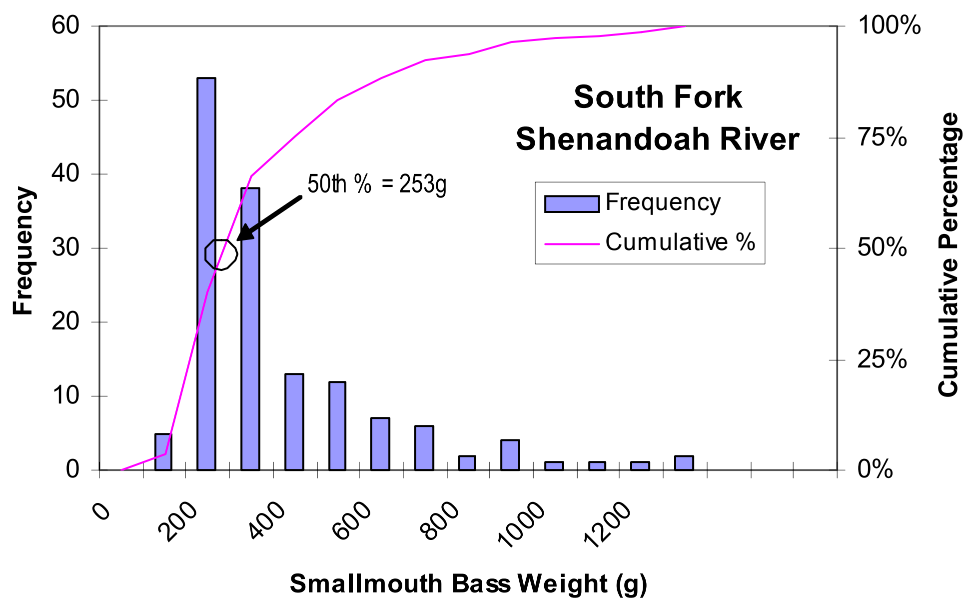


Figure 2-6. Histogram of Smallmouth Bass Size (g) in the South Fork Shenandoah River.

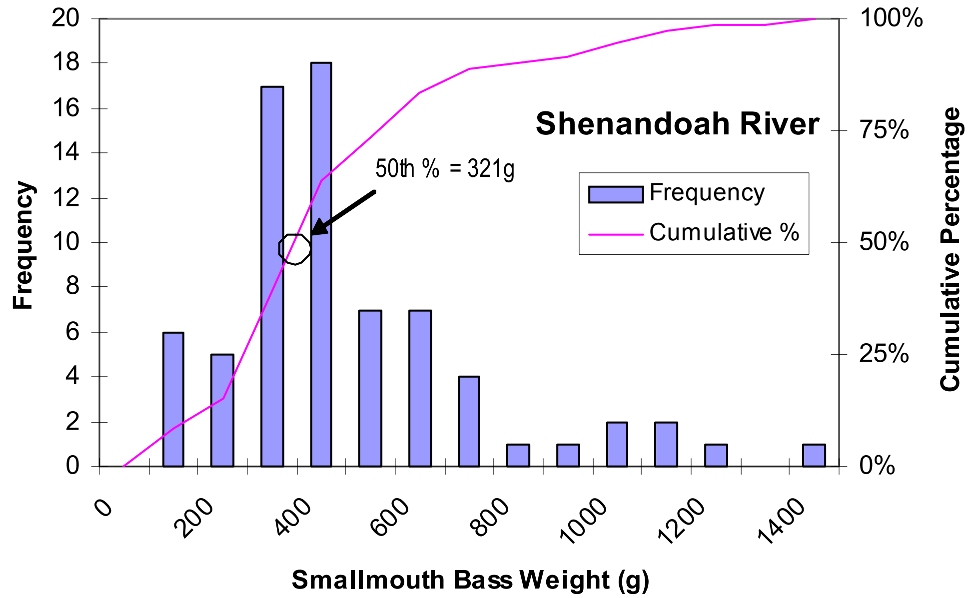


Figure 2-7. Histogram of Smallmouth Bass Size (g) in the Shenandoah River.

Normalized fish methylmercury concentrations also varied by distance downstream from DuPont (Table 2-2). This difference was due to the varying levels of mercury contamination in the system, and tracked well with total mercury concentrations in the water column (Figure 2-8). Mercury concentrations in the water column and in fish tissue increase sharply for approximately the first 10 miles downstream of DuPont (to the town of Crimora, VA). Mercury concentrations then decrease throughout the remaining length of the South River. At approximately 25 miles downstream, the South River joins with the North River to form the South Fork Shenandoah River in Port Republic, VA. Mercury concentrations decrease sharply at this point due to dilution from the additional North River flow and clean sediment load. Throughout the South Fork Shenandoah River, mercury concentrations remain relatively constant.

Table 2-2. Mercury in Size-normalized Smallmouth Bass and Water Column in the South River and South Fork Shenandoah River.

Station	Distance Downstream (miles)	Normalized Fish Tissue Methylmercury[1] (ug/g)	Water Column Total Hg[1] (ng/L)
1BSTH026.12 (reference)	-1.02	**0.29** ± 0.19 (38)	**1.75** ± 0.62 (33)
1BSTH023.73	1.37	**0.90** ± 0.55 (18)	**13.1** ± 7.4 (18)
1BSTH022.75	2.35	**1.92** ± 1.08 (16)	**35.5** ± 25.8 (32)
1BSTH020.44	4.66	**2.16** ± 0.83 (19)	**83.1** ± 53.3 (32)
1BSTH014.49	10.61	**2.69** ± 1.35 (28)	**84.3** ± 63.5 (14)
1BSTH004.21	20.89	**1.76** ± 0.65 (19)	**59.1** ± 38.1 (16)
1BSSF100.10	27.76	**0.95** ± 0.32 (70)	**14.6** ± 12.0 (16)
1BSSF078.20	49.62	**0.71** ± 0.62 (28)	**11.9** ± 12.2 (31)
1BSSF054.20	73.66	**1.01** ± 0.39 (28)	**16.3** ± 25.3 (16)
1BSSF037.60	90.26	**0.78** ± 0.43 (19)	**11.0** ± 19.2 (31)
All sites (excluding reference)	NA	**1.33** ± 0.96 (245)	**35.7** ± 43.2 (206)

[1] Mercury values represent mean ± standard deviation, with number of samples in parentheses. Fish tissue values were normalized to a 218 g fish, the 50% probability size fish in the South River.

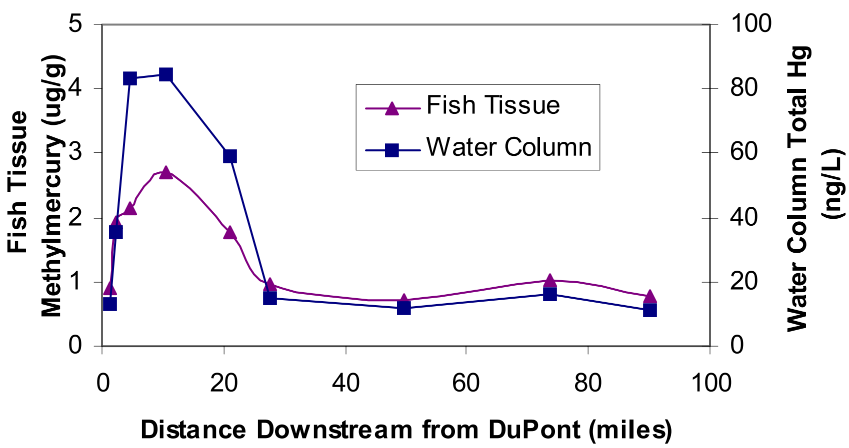


Figure 2-8. Size-normalized Fish Tissue Methylmercury and Water Column Mercury in the South River and South Fork Shenandoah River Downstream from DuPont in Waynesboro, VA.

2.4.3.3. Empirical Bioaccumulation Model Development

As previously discussed, site-specific information on the factors controlling mercury methylation and bioaccumulation did not allow the development of a mechanistic bioaccumulation model for the South River. However, fish tissue and water column mercury data collected by VADEQ in the South River and South Fork Shenandoah River provided a robust dataset for developing an empirical model. The developed model represents the empirical relationship between total mercury in the water column and methylmercury in fish tissue of smallmouth bass, the top trophic level consumer in the South River aquatic ecosystem. Figure 2-9 depicts the key processes of methylation, biological uptake, and trophic transfer that lead to the bioaccumulation of methylmercury in upper trophic level fish. Because the factors controlling each of these steps are not completely understood in the South River system, the empirical model directly relates the input and the ultimate outcome from this series of steps. This is not to say that the intervening steps and processes are unimportant. Rather, the empirical model inherently incorporates these processes under the prevailing environmental conditions present in the South River and South Fork Shenandoah River.

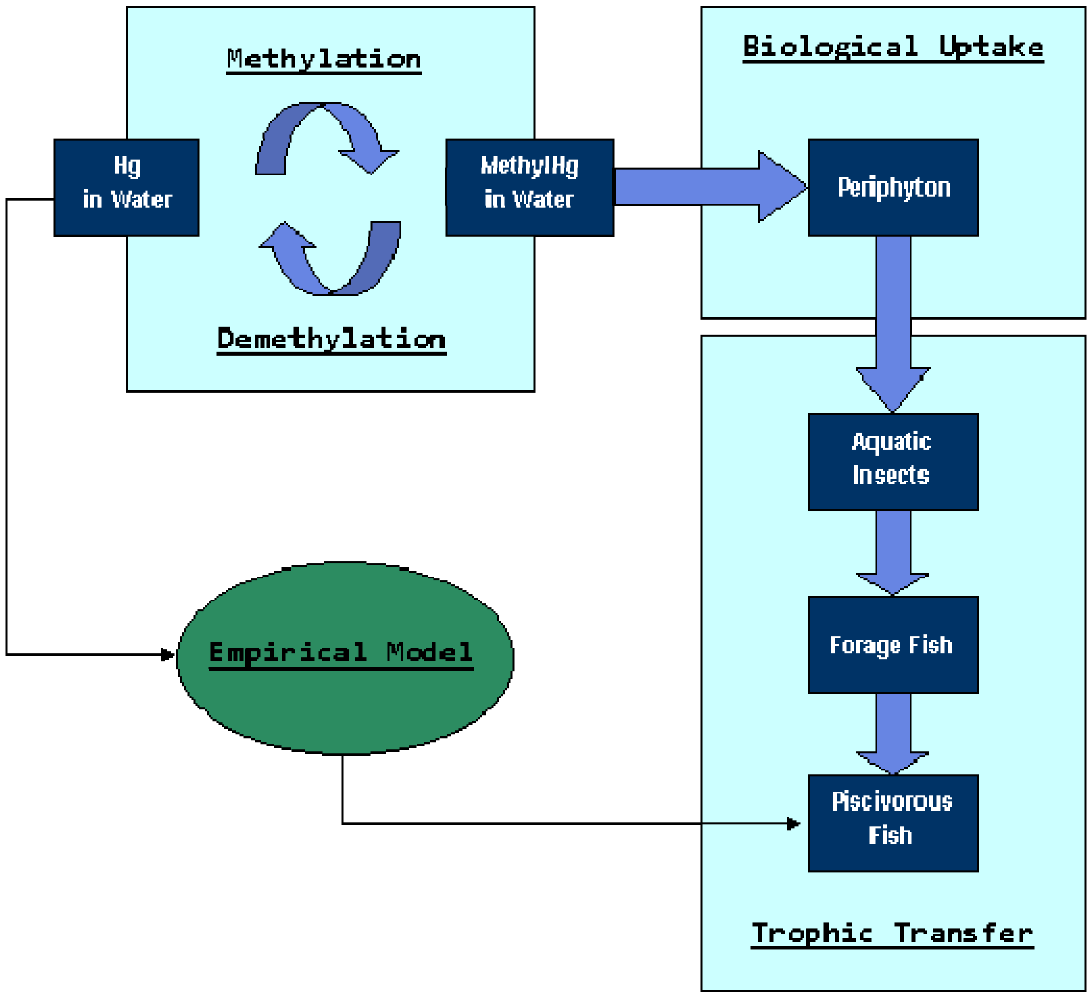


Figure 2-9. Simplified Conceptual Model of Mercury Bioaccumulation and an Empirical Bioaccumulation Model.

The empirical bioaccumulation model was developed from colocated fish tissue and water column mercury data collected at sites that varied in mercury contamination. This allowed the analysis of the water column mercury to fish tissue relationship across a range of mercury contamination levels. Figure 2-10 shows this relationship across nine sites in the South River and South Fork Shenandoah River. The relationship appeared to be non-linear, with the rate of increase in fish tissue methylmercury levels slowing as total mercury in the water column increased. This finding is consistent with the findings of Southworth *et al.* (2004), who demonstrated that ratios of mercury in fish tissue to total mercury in the water column (i.e., total mercury bioaccumulation factors) decreased with increasing mercury contamination levels.

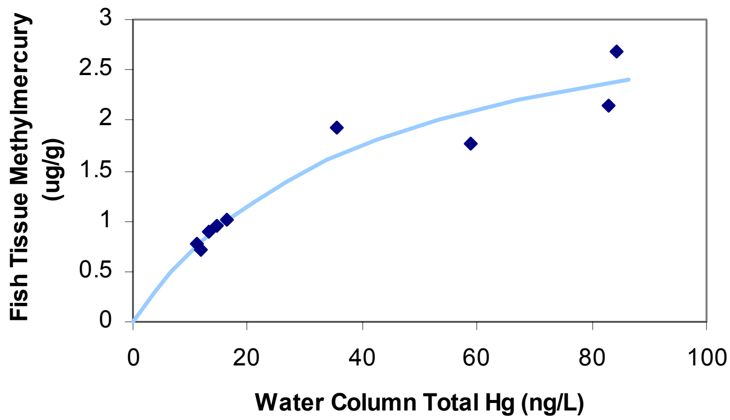


Figure 2-10. Relationship Between Size-normalized Fish Tissue Methylmercury Levels and Total Mercury in the Water Column of the South River and South Fork Shenandoah River.

Southworth *et al.* (2004) also hypothesized that the percent methylmercury to mercury relationship in water, and thus the related fish tissue to water column mercury relationship, would fit the form of the Michaelis-Menten equation (Figure 2-11). The Michaelis-Menten equation is a standard relationship used in biochemistry to describe the reaction rate of enzyme catalyzed reactions (Darnell *et al.,* 1990). The relationship between fish tissue methylmercury and water column mercury in the South River/South Fork Shenandoah River system (Figure 2-10) appears to fit the shape of this standard Michaelis-Menten curve (Figure 2-11). In addition to the empirical fit of the data, the underlying mechanisms involved in bioaccumulation support the fit of the data to this form. The primary step from water column mercury to bioaccumulation in fish is the methylation of inorganic mercury (Sorensen *et al.,* 1990). This step is most often carried out by sulfate-reducing bacteria (Winfrey and Rudd, 1990), and would likely be an enzyme-mediated reaction that is dependent upon the concentration of the reaction substrate (in this case, inorganic mercury). For these reasons, the Michaelis-Menten equation was used as the basis of the empirical model describing the water column mercury to fish tissue methylmercury relationship.

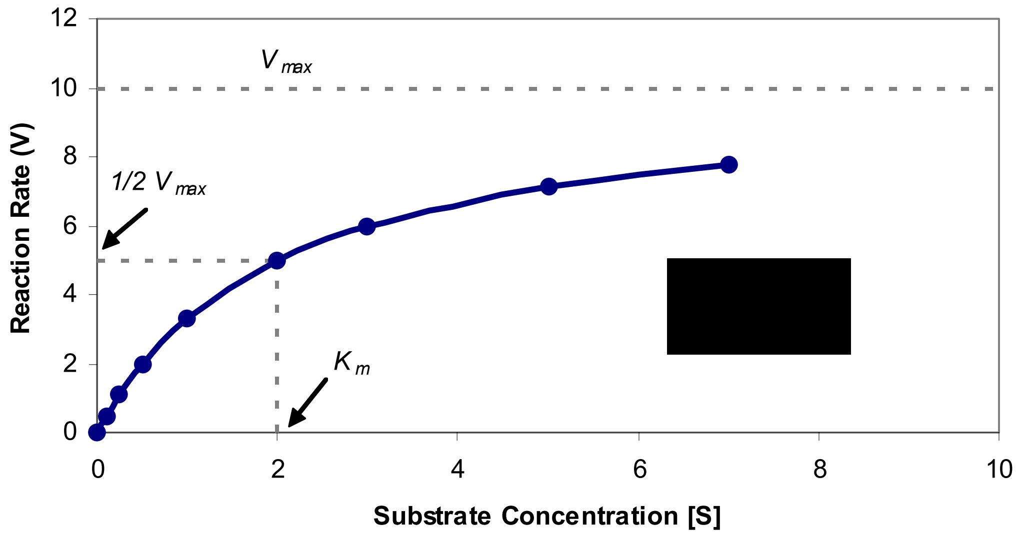


Figure 2-11. Standard Michaelis-Menten Equation for Enzyme-mediated Reactions.

The traditional approach to linearization of the Michaelis-Menten equation is an inverse plot, or Lineweaver-Burk plot (Lineweaver and Burk, 1934). This approach plots the inverse of the reaction rate (or in our case, the fish tissue concentration) on the y-axis and the inverse of the substrate concentration (or in our case, the water column concentration) on the x-axis. Using this approach, the water column mercury to fish tissue methylmercury relationship was linearized (Figure 2-12). The South River/South Fork Shenandoah River data fit the linearized Michaelis-Menten equation extremely well, with an R^2 of 0.9562. The resulting equation to describe the water column mercury to fish tissue methylmercury relationship was:

$$Hg_{Water} = \frac{a}{\left(\frac{1}{Hg_{Fish}}\right) - b} \qquad [2\text{-}3]$$

Where,

Hg_{Water} = Total mercury concentration in the water column (ng/L),

Hg_{Fish} = Methylmercury concentration in size-normalized smallmouth bass from South River/South Fork Shenandoah River (ug/g),

a = Slope of the Lineweaver-Burk plot, and

b = Intercept of the Lineweaver-Burk plot.

The above equation was used as an empirical bioaccumulation model to predict target water column concentrations of total mercury that would be protective of the 0.3 ppm methylmercury fish tissue criterion. This equation was evaluated independently for the South River, South Fork Shenandoah River, and mainstem Shenandoah River. Fish sizes generally increase as the size of the rivers increases downstream, so the human health risk of eating larger contaminated fish would also increase. This was reflected in developing separate target water column concentrations for each river based on the respective fish sizes in the different rivers (see Section 2.4.3.2). Table 2-3 shows the resulting target water column concentrations of total mercury in each river. In the South River, the target water column concentration was calculated to be 3.8 ng/L total mercury. The target concentration was 3.2 ng/L in the South Fork Shenandoah River and 2.5 ng/L in the mainstem Shenandoah River. Based on the empirical bioaccumulation model and site-specific fish size, fish methylmercury, and water column total mercury levels, these target water column concentrations should be protective of the 0.3 ppm fish tissue methylmercury criterion. Accordingly, the mercury TMDLs were developed to meet these instream target water column concentrations.

While the empirical bioaccumulation model exhibited good overall fit, there are uncertainties associated with predicting restoration outcomes from such an empirical model. The model is based on existing conditions in the river, including methylation/demethylation rates, bioaccumulation rates, and existing food web structure. If these variables change in the future, the empirical relationship between total mercury in the water column and fish tissue methylmercury will likely change. The influence of stored mercury in bed sediments also adds to uncertainty in the exact trajectory of restoration. Due to these and other uncertainties, VADEQ anticipates implementing this TMDL using adaptive implementation strategies that will be flexible and responsive to new information (see Section 5.2).

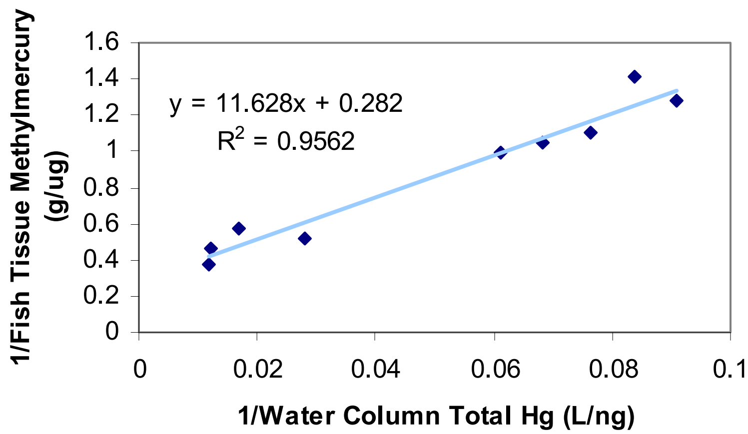


Figure 2-12. Linearized Michaelis-Menten Inverse Plot of Size-normalized Smallmouth Bass Methylmercury Levels and Water Column Total Mercury Levels in the South River and South Fork Shenandoah River.

Table 2-3. Target Water Column Concentrations Protective of 0.3 ppm Fish Tissue Criterion.

River	Normalized Fish Size (g)	*a*	*b*	Target Water Column Concentration Protective of 0.3 ppm Fish Tissue Criterion (ng/L)
South River	218	11.628	0.282	3.8
South Fork Shenandoah River	253	10.02	0.2429	3.2
Shenandoah River	321	7.8971	0.1915	2.5

2.4.3.4. Evaluation of Alternative Empirical Relationships

The relationship between total mercury in the water column and methylmercury in fish tissue was used to develop target water column concentrations for the South River mercury TMDL. An empirical bioaccumulation model in the form of the linearized Michaelis-Menten equation was used to describe this relationship. Other relationships and other models were also considered, but this combination produced the best empirical fit. Table 2-4 compares the R^2 values for other models and for relationships between fish tissue methylmercury and other water column constituents. Intuitively, other constituents in the water column such as methylmercury might be expected to better predict methylmercury concentrations in fish, however, these other relationships were not as strong as between total mercury in the water column and methylmercury in fish tissue.

Table 2-4. Empirical Fit of Various Models Relating Water Column Mercury Levels to Methylmercury in Fish Tissue.

Constituent	Model Fit (R^2)		
	Linear Model	Power Model	Michaelis-Menten Model
Total Mercury	0.8865	0.9362	**0.9562**
Dissolved Mercury	0.5747	0.6527	0.7195
Total Methylmercury	0.6077	0.7121	0.8536
Dissolved Methylmercury	0.5092	0.5305	0.6625

3. SOURCE ASSESSMENT

Sources of mercury in the South River watershed include both point sources and nonpoint sources. Point sources include industrial and municipal wastewater treatment facilities, and nonpoint sources include atmospheric deposition, runoff from background or contaminated land surfaces, groundwater and interflow from background or contaminated land areas, and channel margin inputs. This section briefly summarizes source assessment information used in the development of the South River mercury TMDL model. More detailed information on the characterization and modeling of mercury sources is described in the USGS report in Attachment 1.

3.1. PERMITTED POINT SOURCES

There are 14 individually permitted point sources in the South River watershed (Table 3-1). Of those, only the industrial and major municipal facilities were included in the South River TMDL mercury model. Minor municipal facilities and water treatment facilities within the South River watershed were not sampled and were not included in the South River TMDL mercury model. None of these facilities are known or expected to be sources of mercury contamination, and the flows from these facilities are small enough that any measured mercury load would be insignificant. If the highest mercury concentration measured in municipal wastewater (7.6 ng/L measured in the Waynesboro STP discharge) were assumed for all of the minor municipal facilities and water treatment facilities, the combined mercury load from these discharges would be <0.005% of the existing mercury load in the South River.

In addition to individually permitted point sources, a number of general permits have been issued in the South River watershed. The number of each general permit type issued in the watershed is shown in Table 3-2. Similarly to minor municipal facilities, the general permits are not expected to be sources of mercury contamination, they are even smaller in flow, they contribute an insignificant load of mercury to the river, and therefore, they were not included in the South River TMDL mercury model.

Table 3-1. Individually Permitted Discharges in the South River Watershed.

Facility Type	Permit No.	Facility Name	Outfall	Max Design Flow (MGD)[1]	River Mile	Receiving Stream
Industrial	VA0002160	Invista	001	5	25.3	South River
			003	NA	25.3	South River
			004	NA	25.3	South River
			006	NA	25.3	South River
			008	NA	25.3	South River
			009	NA	0.55	South River, U.T.
			010	NA	0.36	South River, U.T.
			011	0.386	25.17	South River
			012	NA	25.3	South River
			013	NA	25.3	South River
			014	NA	25.3	South River
	VA0001767	Alcoa Packaging LLC	001	3.2	4.37	South River
	VA0002402	Former Genicom	001	0.216	21.94	South River
Major Municipal	VA0066877	Stuarts Draft WWTP	001	4	38.88	South River
	VA0025151	Waynesboro STP	002[2]	6	23.22	South River
			001	4	23.54	South River
Minor Municipal	VA0027901	Harriston STP	001	0.1	8.2	South River
	VA0028037	Skyline Swannanoa	001	0.15	2.96	South River, U.T.
	VA0065374	Grottoes STP	001	0.4	1.59	South River
	VA0088226	Hugh K Cassell Elementary School	001	0.011	0.35	Porterfield Run, U.T.
	VA0067962	Vesper View STP	001	0.1	16.04	South River
	VA0088943	Blue Ridge MHC LLC	001	0.024	14.2	South River
	VA0023400	DOC - Cold Springs Correctional Unit 10	001	0.06	1.99	Poor Creek
	VA0088986	Black Rock Mobile Home Park	001	0.04	0.02	South River, U.T.
Water Treatment	VA0092100	Coyner Springs WTP	001	0.414	1.29	South River, U.T.

[1] For industrial facilities, such as Invista, the listed flows are not maximum design flows, but represent the maximum monthly average flow that was used to develop permit limits for that outfall. For outfalls that contain only stormwater, the maximum design flow is listed as NA, or not applicable.
[2] This outfall will replace outfall 001 when wastewater treatment plant updgrades are completed.

For industrial and major municipal point sources that were included in the South River mercury model, discharge sampling for mercury was conducted to provide accurate model inputs. Since the former DuPont plant site was the original source of mercury contamination, a detailed monitoring program of mercury from this site was essential. As previously described (Section 2.2), DuPont continues to own the property, but the manufacturing assets, including the permitted discharge outfalls, are now owned by Invista. As a part of Resource Conservation and Recovery Act (RCRA) facility investigations, DuPont has conducted mercury monitoring of the Invista stormwater and wastewater outfalls since 2004 (Table 3-3). These data were used to characterize mercury inputs under existing condition scenarios as described in Attachment 1. While each Invista outfall was independently included in the South River model, flow and mercury monitoring results show that the majority of mercury load from the plant site is through outfalls 001, 011, and 008.

Table 3-2. General Permits in the South River Watershed.

General Permit Type	# of Permits
Single Family Home	9
Industrial Stormwater	16
Ready-mix Concrete	1
Non-metallic Mineral Mining	2
Cooling Water	1
Land Application	3
Confined Animal Feeding Operation - Poultry	10
Confined Animal Feeding Operation - Dairy	1

Table 3-3. Mercury Monitoring at Invista Outfalls.

Outfall #	Outfall Description	Baseflow Hg Monitoring (ng/L)[1]		Stormflow Hg Monitoring (ng/L)[1]	
		Range	Average	Range	Average
001	Primary outfall for treated process wastewater and untreated non-process wastewater	20 - 133	51	11 - 262	93
003	Steam condensate, stormwater, Baker Spring and well water	5 - 219	43	1 - 312	118
004	Stormwater and well test water	14 - 37	22	7 - 129	42
006	Stormwater and well test water	12 - 22	16	12 - 33	22
008	Stormwater	6 - 2492	222	21 - 591	190
009	Stormwater	No baseflow		30 - 154	82
010	Stormwater and well test water	No baseflow		87 - 449	238
011	Untreated non-process wastewater and stormwater	39 - 23808	2051	44 - 3400	889
012	Stormwater	Not sampled; estimated from 010 results			
013	Overflow of consolidated sump internal outfall	Not sampled; estimated from 001 results			
014	Overflow of waste treatment sump	Not sampled; estimated from 001 results			

[1] Summaries of mercury monitoring results represent outfall samples collected by DuPont from 11/2004 through 3/2007. DuPont has continued sampling, but additional data were not used in TMDL development.

With the exception of the Invista discharge, no other point source discharges are known sources of mercury contamination to the South River. Due to their large flows or location within the contaminated flood plain, however, additional facilities could contribute measureable amounts of mercury to the river. For this reason, mercury loadings from all industrial and major municipal facilities were included in the South River TMDL mercury model. These industrial and major municipal point sources that were not expected to be significant sources of mercury were only sampled once to estimate mercury loadings (Table 3-4). Overall loads from these facilities were relatively small, but did exceed the protective instream target concentration of 3.8 ng/L at two facilities. Measured mercury concentrations in these discharges were used to characterize mercury inputs under existing condition scenarios as described in Attachment 1.

Table 3-4. Mercury Concentrations Measured in Point Source Discharges.

Permit #	Facility Name	Sample Date	Mercury Concentration (ng/L)
VA0001767	Alcoa Packaging LLC	10/17/2006	18.3
VA0002402	Former Genicom	10/17/2006	0.2
VA0066877	Stuarts Draft WWTP	10/17/2006	0.7
VA0025151	Waynesboro STP	10/17/2006	7.6

3.2. NONPOINT SOURCES

Nonpoint sources of mercury to the South River include atmospheric deposition, runoff from background or contaminated land surfaces, groundwater and interflow from background or contaminated land areas, and channel margin inputs. Attachment 1 describes how each of these sources was characterized in the South River mercury TMDL model. In general, initial estimates for each source were made based on available monitoring information. If necessary, those initial estimates were adjusted during the model calibration process to obtain agreement between simulation results and observed monitoring data. Table 3-5 shows the final model inputs for nonpoint sources.

Table 3-5. Nonpoint Sources of Mercury to the South River.

Nonpoint Hg Source	Data Used to Determine Initial Concentrations	Model Input
Atmospheric deposition on river surface	USEPA (USEPA, 2007a)	Precip. concentration = 21.8 ng/L
Groundwater from uncontaminated land areas	THG_F at Waynesboro gage (01626000)	Groundwater dissolved HG = 0.7 ng/L
Groundwater from HG contaminated flood plain	Flood-plain groundwater samples, plus calibration	Groundwater dissolved HG = 1.3 - 2.9 ng/L
Interflow	Precipitation THG_F (USEPA, 2007a) and calibration	Calibrated values from 10.0 to 16.7 ng/L
Soil attached HG runoff from uncontaminated pervious and impervious land surfaces	Soil samples from uncontaminated areas	THG_{Sed} = 0.07 ug/g for all uncontaminated HRUs
Soil attached HG runoff from contaminated pervious land surfaces	Soil samples within respective reaches	THG_{Sed} concentration varies by reach and HRU from (7.6 to 16.7 ug/g)
Channel margin inputs	THG at Waynesboro (01626000), Dooms (01626920), and Harriston (01627500)	Calibrated values of sediment attached HG added to water column within each RCHRES

4. TMDL DEVELOPMENT

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991a). To achieve this objective, a water quality model was developed and calibrated to simulate existing conditions within the South River. Following successful calibration and simulation of existing conditions, future conditions were then projected, and various reduction scenarios were adjusted until water quality standards were met. Attachment 1 describes in detail the model development, calibration, and simulation of existing conditions, future conditions, and various allocation scenarios. This section briefly summarizes those results.

4.1. WATER QUALITY MODELING

The USGS developed a water quality model of the South River using the Hydrological Simulation Program-Fortran (HSPF) modeling platform. This water quality model simulates streamflow, sediment transport, and mercury transport in the South River. The hydrologic portion of HSPF generates time series of streamflow in response to precipitation, evapotranspiration, and movement of water from the land surface to stream networks through runoff, groundwater flow, and interflow. The sediment portion of HSPF simulates sediment loading from pervious and impervious land surfaces through washoff and scouring. Within the stream, HSPF simulates sediment transport, deposition, and resuspension. The mercury portion of the model simulates mercury loading from point sources, atmospheric deposition, runoff from background or contaminated land surfaces, groundwater and interflow from background or contaminated land areas, and channel margin inputs. Within the river, HSPF simulates mercury sorption/desorption to/from suspended particles, deposition and resuspension of sediment-associated mercury, and downstream advection. The USGS individually calibrated and verified the hydrologic, sediment transport, and mercury transport portions of the model with observed data to ensure that the model was effectively predicting instream flow, sediment, and mercury concentrations. Additional details of the South River mercury model are described in Attachment 1.

4.2. EXISTING CONDITIONS

Following calibration of the South River hydrologic, sediment, and mercury model, the model was used to simulate existing conditions. Existing conditions were simulated using weather and point source inputs for April 1, 2005 to March 31, 2007. Figure 4-1 and Figure 4-2 show simulated mercury concentrations in the South River under existing conditions. Mercury concentrations above the former DuPont plant site (at the Waynesboro gage) ranged from 0.6 to 53 ng/L, but 90-d median values were below the instream target of 3.8 ng/L. Within the contaminated reach (at Harriston) mercury concentrations ranged from 12 to over 5000 ng/L and were consistently well above the instream target. The median mercury concentration at Harriston was 91 ng/L under existing conditions, compared to 1.6 ng/L at Waynesboro.

Simulated results showed that mercury fluxes in the South River increased sharply from the former DuPont plant site downstream to Dooms and then stabilized (Figure 4-3). Mercury loadings above Waynesboro were relatively low (1 kg/yr). From Waynesboro to Hopeman Parkway, mercury loadings increased to 60 kg/yr. Loadings were highest in the reach from Hopeman Parkway to Dooms (87 kg/yr). Below Dooms, mercury loadings decreased, with 36 kg/yr entering the reach ending at Harriston and only 6 kg/yr entering the reach ending at Port Republic. These simulation results are consistent with other findings of the SRST that the majority of mercury loadings to the South River occur from the former DuPont plant site to Dooms.

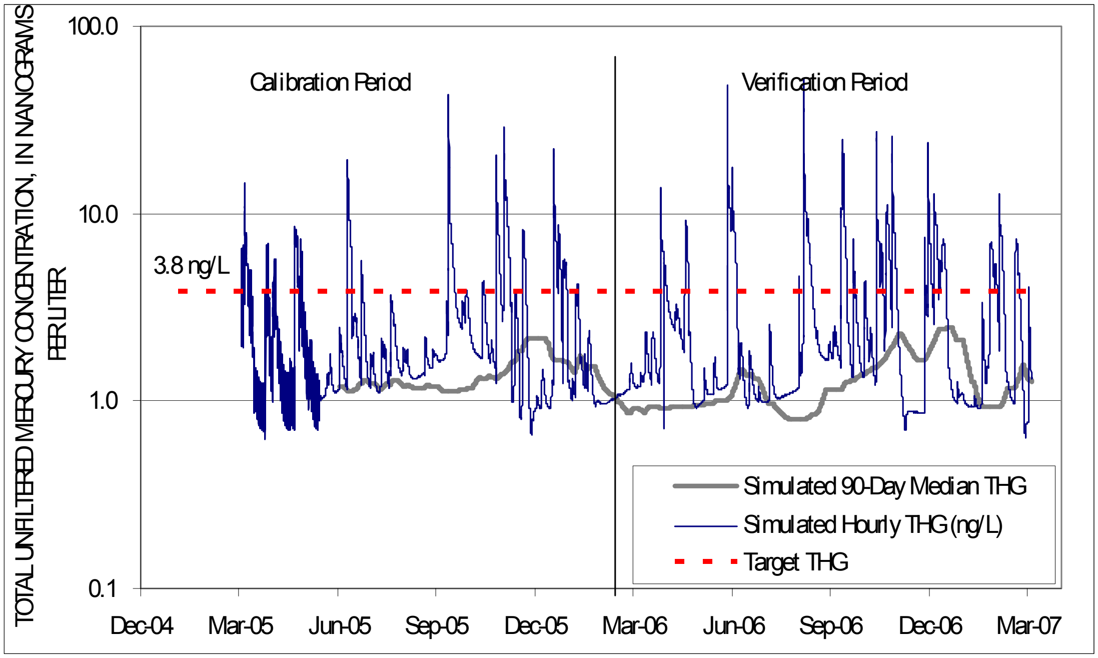


Figure 4-1. HSPF Model Simulation of Mercury Concentrations in the South River at Waynesboro Under Existing Conditions (April 2005 - April 2007).

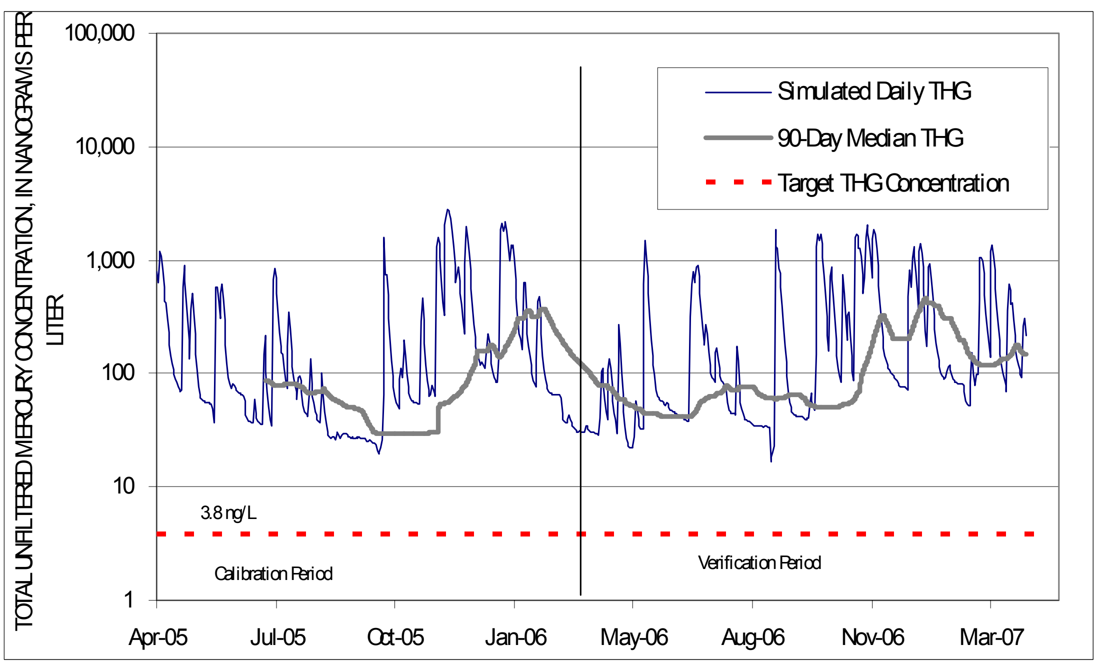


Figure 4-2. HSPF Model Simulation of Mercury Concentrations in the South River at Harriston Under Existing Conditions (April 2005 – April 2007).

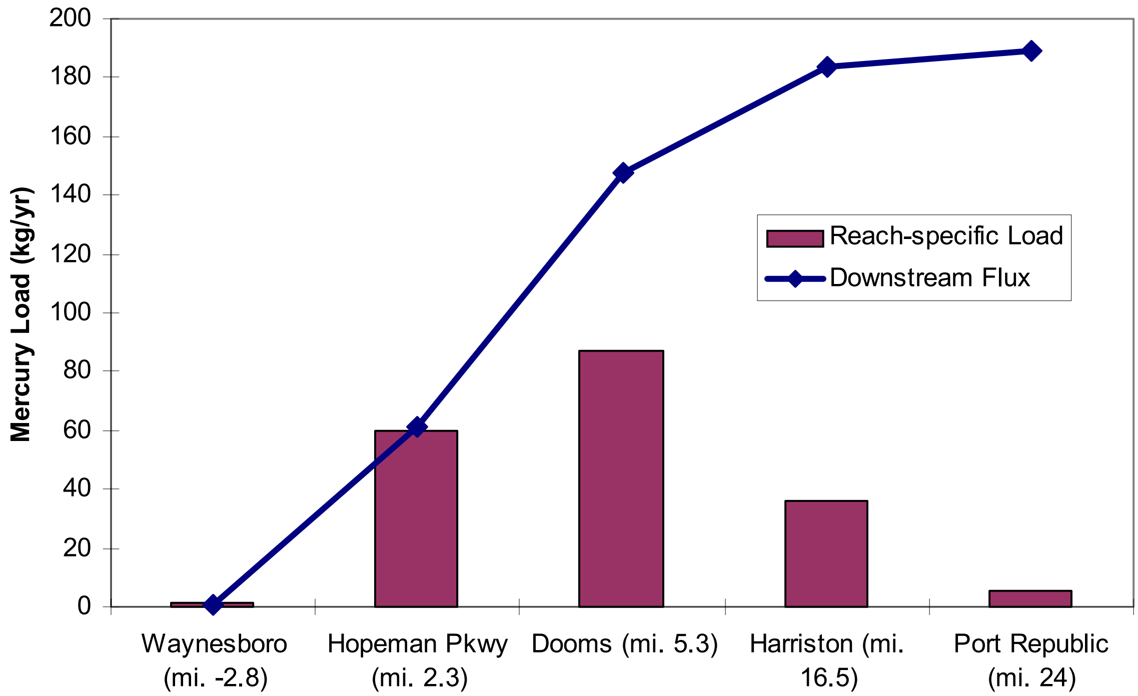


Figure 4-3. Mercury Loadings and Downstream Flux in the South River.

The sources of mercury loadings to the South River under existing conditions are shown in Figure 4-4. The majority of mercury (84%) was determined to be from channel margin inputs, which include bank erosion, disturbance, collapse, or other mechanisms that can transfer mercury contaminated material from the contaminated channel margins to the water column or river bed. The second most prevalent mercury source (at 15%) was sediment-attached mercury carried in runoff from the land surface. This includes a small portion from naturally occurring or atmospherically deposited mercury from uncontaminated areas (4%), but primarily represents mercury from the contaminated flood plain (96%). All other sources were relatively small with respect to annual loadings, however, their contribution can have a significant impact on daily water column concentrations of mercury. For instance, point sources contributed only 0.34% of annual average mercury loads, but reduction scenarios that reduced point source concentrations to 3.8 ng/L reduced median simulated mercury concentrations in the river by as much as 14%. In addition, reductions in channel margin and runoff sources of mercury alone were insufficient to meet TMDL targets. Reductions from point sources were required, even though total annual loading from those sources are small in comparison to other sources.

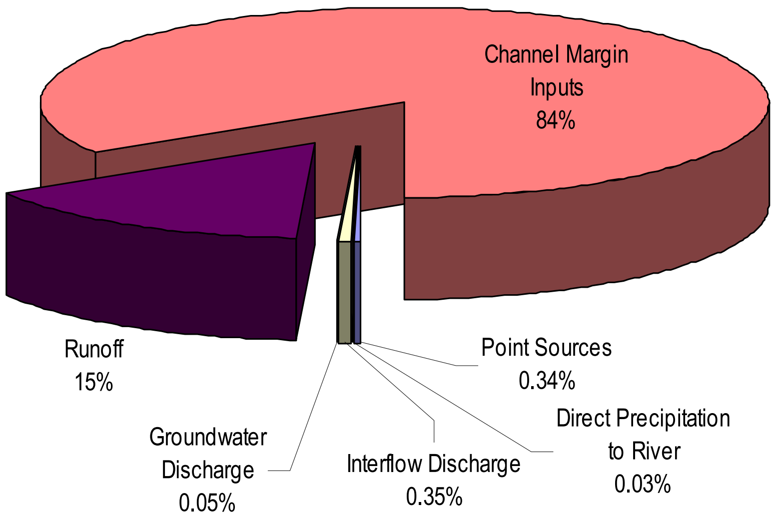


Figure 4-4. Source Contributions of Mercury to the South River Under Existing Conditions.

4.3. ALLOCATION SCENARIOS

Following calibration and evaluation of the South River mercury model under existing conditions, various future reduction scenarios were simulated to determine the level of reductions needed to meet instream water quality targets. Table 4-1 shows the various scenarios that were simulated. The results of each scenario are described in detail in Attachment 1. In general, none of the scenarios were successful in meeting the instream water quality target except for Scenario 4B. This scenario became the TMDL allocation scenario for the South River.

Table 4-1. Simulated Allocation Scenarios for Mercury in the South River.

Scenario Type	Scenario #	Scenario Conditions
Existing conditions	1	Calibrated model under existing conditions; All current mercury loads included
Future conditions	2	Point source flows increased to maximum permitted or design flows; Invista outfall 011 directed to the South River; Precipitation and interflow mercury inputs reduced by 19%
Single source reductions	3A	All future conditions in effect; Point source concentrations reduced to target instream concentration (3.8 ng/L)
	3B	All future conditions in effect; Channel margin inputs reduced by 100%
	3C	All future conditions in effect; Runoff cleaned to background conditions (reduced by 96%)
Multiple source reductions	4A	All future conditions in effect; Channel margin inputs reduced by 100%; Runoff cleaned to background conditions (reduced by 96%)
	4B (TMDL Scenario)	All future conditions in effect; Channel margin inputs reduced by 100%; Runoff cleaned to background conditions (reduced by 96%) Point source concentrations reduced to target instream concentration (3.8 ng/L)

4.4. SOUTH RIVER TMDL

A TMDL considers all sources contributing mercury to the South River, including point (or direct) and nonpoint (or indirect) sources. The TMDL can be shown to represent these sources as defined in the following equation:

$$TMDL = WLA + LA + MOS \qquad [4\text{-}1]$$

Where,

WLA = wasteload allocation (point source contributions),

LA = load allocation (nonpoint source contributions), and

MOS = margin of safety.

The objective of the mercury TMDL for the South River is to determine what reductions in mercury loadings from point and nonpoint sources are required to meet state water quality standards. As described in Section 2.4, the applicable water quality standard is a fish tissue methylmercury concentration of 0.3 ppm, and the instream water quality target to achieve this goal was determined to be a 90-d median mercury concentration of 3.8 ng/L in the water column. Allocation scenario 4B successfully met this criterion and was selected as the TMDL allocation scenario. This scenario calls for an overall 99% reduction in mercury loadings from existing conditions (Table 4-2). Under this reduction scenario, the average annual mercury load at the outlet of the South River is 2,029 g/yr. This is the annual expression of the mercury TMDL for the South River.

The TMDL scenario includes elimination of channel margin inputs, a 96% reduction from runoff, an 83% reduction from point sources, and a 19% reduction from interflow and direct precipitation. The 83% point source reduction represents all point sources reducing mercury concentrations in the discharge to 3.8 ng/L. The 96% reduction in runoff loading represents returning flood plain soils to background mercury levels of 0.07 ug/g on average. The 19% reduction in interflow and direct precipitation represents the predicted reductions achieved through USEPA's Clean Air Interstate Rule and the Clean Air Mercury Rule.

Table 4-2. Mercury Load Reductions Necessary to Meet TMDL Conditions in the South River.

Source	Annual Hg Loading Under Existing Conditions (g/yr)	Annual Hg Loading Under TMDL Conditions (g/yr)	Percent Reduction (%)
Point Sources	650	112	83%
Direct Precipitation to River	55	45	19%
Interflow	667	558	19%
Groundwater	99	99	0%
Runoff	29,237	1,216	96%
Channel Margin	158,713	0	100%
Total	**189,421**	**2,029**	**99%**

4.4.1. Wasteload Allocations

Wasteload allocations quantify the amount of mercury allowed in point source discharges under the TMDL scenario. Table 4-3 shows the wasteload allocations for industrial and major municipal facilities in the South River watershed. As described in Section 3.1, minor municipal facilities and facilities covered under general discharge permits are considered insignificant sources of mercury and were not assigned wasteload allocations.

Calculated wasteload allocations were expressed as an average annual load, an average daily load, and a maximum daily load. All three expressions are consistent with the TMDL scenario described above (scenario 4B). In this scenario, point sources were modeled as discharging continuously at the maximum design flow and instream water quality target of 3.8 ng/L. Based on this scenario, the annual expression of the wasteload allocation was calculated by multiplying the maximum design flow of each facility by the instream water quality target (and appropriate unit conversions) and summing the calculated loads for a year. The average daily expression of the wasteload allocation was then calculated by dividing the annual allocation by 365. The maximum daily expression of the wasteload allocation was statistically derived to define the allowable variability around average daily loads that would be protective of the annual allocation. The following formula from USEPA's *Technical Support Document for Water Quality-Based Toxics Control* (USEPA, 1991b) and USEPA's draft *Options for Expressing Daily Loads in TMDLs* (USEPA, 2007b) was used to calculate maximum daily wasteload allocations for each facility.

$$MDL = LTA * \exp(Z_p \sigma_y - 0.5\sigma_y^{\,2}) \qquad [4\text{-}2]$$

Where,

MDL = Maximum daily load,

LTA = Long term average, which in this case is the average daily load,

Z_p = p^{th} percentage point of the standard normal distribution (95$^{\text{th}}$ percentile was used),

$\sigma_y = \sqrt{\ln(CV^2 + 1)}$, and

CV = Coefficient of variation (estimated at 0.6 for each facility).

Wasteload allocations for continuous discharges were calculated as described above. The wasteload allocation for Invista's stormwater discharges was calculated differently. Because the TMDL scenario calls for clean up of flood plain areas to background levels, the wasteload allocation for stormwater discharges was based on the modeled runoff loads from an uncontaminated area with similar landuse. An annual lumped allocation for Invista's stormwater discharges was calculated as the mercury runoff load from 113 acres of high intensity impervious urban landuse modeled during the 2-yr TMDL simulation period, divided by 2. The daily average wasteload allocation was then calculated as the annual load divided by 365. The maximum daily wasteload allocation was determined as the 95$^{\text{th}}$ percentile of modeled daily loads from this land area during the 2-yr TMDL simulation period.

Table 4-3. Mercury Wasteload Allocations in South River TMDL.

Permit No	Facility Name	Outfall	Max Design Flow (MGD)[1]	Target Hg Conc. (ng/L)	Wasteload Allocation		
					Annual (g/yr)	Average Daily (g/d)	Maximum Daily (g/d)
VA0002160	Invista[2]	001	5	3.8	26	0.072	0.15
		011	0.386	3.8	2.0	0.0056	0.012
		Combined stormwater flow	NA	NA	13	0.036	0.11
				Subtotal	41	0.114	0.27
VA0001767	Alcoa Packaging LLC	001	3.2	3.8	17	0.046	0.10
VA0002402	Former Genicom	001	0.216	3.8	1.1	0.0031	0.007
VA0066877	Stuarts Draft WWTP	001	4	3.8	21	0.058	0.12
VA0025151	Waynesboro STP	002	6	3.8	31	0.086	0.18
				Total	**112**	**0.306**	**0.69**

[1] For industrial facilities, such as Invista, the listed flows are not maximum design flows, but represent the maximum monthly average flow that was used to develop permit limits for that outfall. For outfalls that contain only stormwater, the maximum design flow is listed as NA, or not applicable.
[2] The wasteload allocations for outfall 001 and 011 represent the non-stormwater flows from these outfalls. The allocation for all stormwater flows (regardless of the outfall) are collectively represented in the row titled "Combined stormwater flow".

4.4.2. Load Allocation

The load allocation (LA) portion of the South River mercury TMDL represents the contributions of mercury from all nonpoint sources. The annual load allocation was calculated as the sum of modeled loads from all nonpoint sources under the TMDL scenario during the 2-yr simulation period, divided by 2. As described above, the TMDL scenario includes elimination of channel margin inputs, a 96% reduction from runoff, and a 19% reduction from interflow and direct precipitation. Based on these reductions, the annual LA was calculated as 1917 g/yr. For daily expressions of the LA (on an average daily basis or a maximum daily basis), the LA was calculated as the difference of the TMDL and the WLA.

4.4.3. Margin of Safety

In the South River mercury TMDL, an implicit margin of safety (MOS) was included. Implicit margins of safety are implemented by using conservative estimates of model input parameters and by using a conservative calibration of water quality parameters. Specific conservative assumptions used in the South River mercury TMDL are described below:

- The empirical bioaccumulation model used to develop the protective instream water quality target was based only on smallmouth bass, the highest trophic level consumer in the South River aquatic food web and the most contaminated fish species. Other fish species that may be consumed by anglers would reach safe levels (<0.3 ppm methylmercury) under reduction scenarios less stringent than the TMDL scenario.

- The use of a non-linear empirical bioaccumulation model provided a more conservative estimate of protective instream water quality targets than the traditional bioaccumulation factor approach. Using the traditional bioaccumulation factor approach (i.e., estimating protective instream water quality targets based on a simple ratio of fish tissue to water column mercury levels at the site), site-specific water quality targets would have ranged from 4.4 to 11.6 ng/L at South River sites rather than the 3.8 ng/L target estimated from the non-linear empirical bioaccumulation model.

- Under the TMDL scenario, point sources were modeled at maximum permitted flow rates for all facilities. While some facilities will likely expand in the future, the likelihood of all facilities reaching their maximum flow rates is small. Average flows from these facilities under existing conditions represented only 27% to 70% of maximum design flows.

- The mercury model was calibrated conservatively, such that error between simulated and observed values was generally in the direction of over prediction. For instance, high end total mercury concentrations, which occur during storms, were simulated higher than the highest observed total mercury concentrations.

4.4.4. TMDL Expressions

The mercury TMDL in the South River is designed to protect human health from mercury exposure through fish consumption. The accumulation of mercury in fish tissue is reflective of exposure over extended time periods, ranging from seasonal to annual. Similarly, human health effects from mercury typically result from long term exposures. Consequently, the most relevant expression of mercury loadings in the South River TMDL is the annual average loading. Table 4-4 shows the South River mercury TMDL expressed as an average annual load. This TMDL represents the sum of mercury loadings to the South River under the TMDL scenario (4B) for the 2-yr simulation period, divided by 2.

Table 4-4. Total Maximum Daily Load of Mercury for the South River Expressed as an Average Annual Load.

Stream	WLA (g/yr)	LA (g/yr)	MOS	TMDL (g/yr)
South River	112	1917	Implicit	2029

In order to comply with current USEPA guidance (USEPA, 2007b), the South River mercury TMDL was also expressed as a daily load in two ways. First, the TMDL was expressed as an average daily load by dividing the average annual load by 365 (Table 4-5). This average daily load represents conditions that, if maintained consistently, would meet the annual loading. Loading conditions, however, are not consistent and are largely influenced by storm events. For this reason, the daily load was also expressed as a daily maximum by evaluating the variability and distribution of simulated daily loads (Table 4-6). The maximum daily load was determined from Equation 4-2 using a 95th percentile and a CV calculated from the mean and standard deviation of simulated daily loads. This calculated maximum daily load of 21.50 g/d was relatively consistent with the empirical 95th percentile of simulated daily loads (18.20 g/d). It should be noted that the maximum daily load expression represents extreme conditions (with a 5% frequency of occurrence), and routine loadings of this level would not meet average annual loadings that are necessary to protect human health and maintain fish tissue levels below 0.3 ppm methylmercury.

Table 4-5. Total Maximum Daily Load of Mercury for the South River Expressed as an Average Daily Load.

Stream	WLA (g/d)	LA (g/d)	MOS	TMDL (g/d)
South River	0.306	5.256	Implicit	5.562

Table 4-6. Total Maximum Daily Load of Mercury for the South River Expressed as a Maximum Daily Load.

Stream	WLA (g/d)	LA (g/d)	MOS	TMDL (g/d)
South River	0.69	20.81	Implicit	21.50

4.4.5. Uncertainty

As with all TMDLs, the modeling used to develop the South River mercury TMDL is subject to various sources of uncertainty. Attachment 1 attempts to quantify some sources of uncertainty in the form of a sensitivity analysis of model parameters. Other sources of uncertainty are much more difficult to quantify, but may have significant impact on modeling results. Some primary examples include the channel margin source and the empirical bioaccumulation model.

The channel margin source was added to the mercury model when initial model runs indicated that sources well-represented within the HSPF framework could not account for the observed instream mercury levels. Other South River Science Team investigations indicated that bank erosion may be a major source of mercury to the river, so the channel margin source was added. HSPF does not have built-in modules to account for bank erosion processes, so a relatively simple approach was used to model these loads (see Attachment 1). This approach does scale channel margin loads to flow, but it does not consider potentially important aspects of bank erosion, such as geomorphology, spatial variation, vegetation, near-bank velocities and shear stresses, erodibility of bank material, or freeze and thaw cycles. Because the channel margin source was determined to be the largest source of mercury to the river (84%), uncertainties in this source could have large impacts on overall model results.

The empirical bioaccumulation model represents another area of unquantifiable uncertainty. Our current understanding of mercury methylation, uptake, and trophic transfer in the South River did not allow the development of a mercury cycling model to link inorganic mercury loads to methylmercury in fish. The model represents a very strong empirical relationship under the existing environmental conditions, but it is unclear that this relationship will hold if environmental conditions change during the implementation of source reductions and remediation strategies.

While channel margin sources and the empirical bioaccumulation model represent unquantifiable sources of uncertainty, they also represent our current best understanding of mercury in the South River ecosystem. To address these and other sources of uncertainty, an adaptive implementation strategy is proposed for this TMDL, so that implementation can flexibly adjust as additional research furthers our understanding of mercury in the South River ecosystem (see

Section 5.2). This TMDL also identifies channel margin sources and mercury methylation and trophic transfer as primary areas of research need. The South River Science Team is well-positioned to fulfill these needs within a reasonable timeframe.

4.5. SOUTH FORK SHENANDOAH AND SHENANDOAH RIVER TMDLS

The mercury impairment that originates in the South River extends downstream for 156 miles and includes the South Fork Shenandoah River and portions of the North Fork Shenandoah River and Shenandoah River. For this reason, TMDLs were also developed for the South Fork Shenandoah River and the Shenandoah River. No TMDL was developed for the small impaired portion of the North Fork Shenandoah River, because the listing of this segment was not based on mercury contamination in the North Fork Shenandoah River but on the possibility of fish movement upstream from the contaminated South Fork Shenandoah River. The implementation of TMDLs and the removal of impairments in the South River, South Fork Shenandoah, and Shenandoah Rivers would also mean the removal of the North Fork Shenandoah River mercury impairment.

Mercury TMDLs in the South Fork Shenandoah and Shenandoah Rivers were developed using a simple mixing model. This mixing model calculated resulting mercury concentrations in the South Fork Shenandoah and Shenandoah Rivers based on mathematically mixing the South River HSPF model output with flow from uncontaminated tributaries to achieve the gaged flow in these rivers. Contributions from uncontaminated tributaries were modeled at 1.81 ng/L, which was the average concentration measured in the North River, an uncontaminated tributary of the South Fork Shenandoah River. Attachment 1 describes the mixing model development and results in more detail.

Results from the South Fork Shenandoah River and Shenandoah River mixing models show that TMDL reductions in the South River will allow downstream rivers to meet the applicable instream water quality targets without further reductions. Figure 4-5 and Figure 4-6 show the successful TMDL scenarios for the South Fork Shenandoah River and Shenandoah River, respectively.

The TMDLs for these downstream rivers were calculated by summing the loads from the mixing model over the 2-yr simulation period, and dividing by 2. Daily average and daily maximum expressions of the TMDL were calculated as described for the South River. Wasteload allocations were equivalent to the wasteload allocations in the South River TMDL, since no additional dischargers on downstream rivers were considered to be significant sources of mercury. The load allocation was calculated as the difference of the TMDL and WLA. Like the South River TMDL, an implicit margin of safety was used. Table 4-7, Table 4-8, and Table 4-9 show the South Fork Shenandoah River and Shenandoah River TMDLs expressed as average annual loads, average daily loads, and maximum daily loads, respectively.

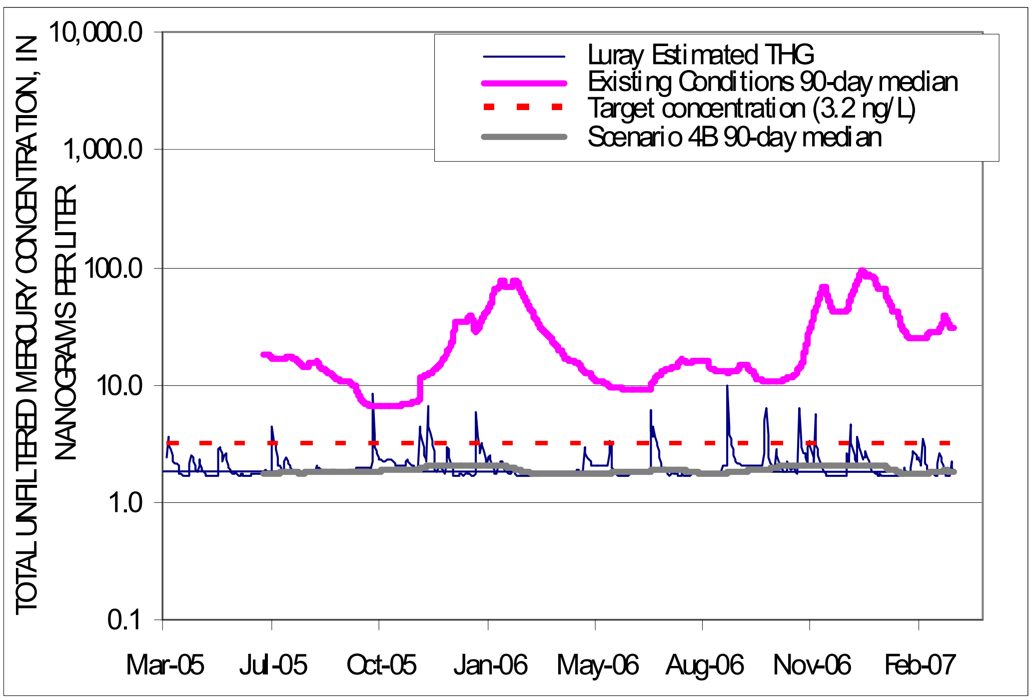


Figure 4-5. Existing Condition and TMDL Scenario for South Fork Shenandoah River.

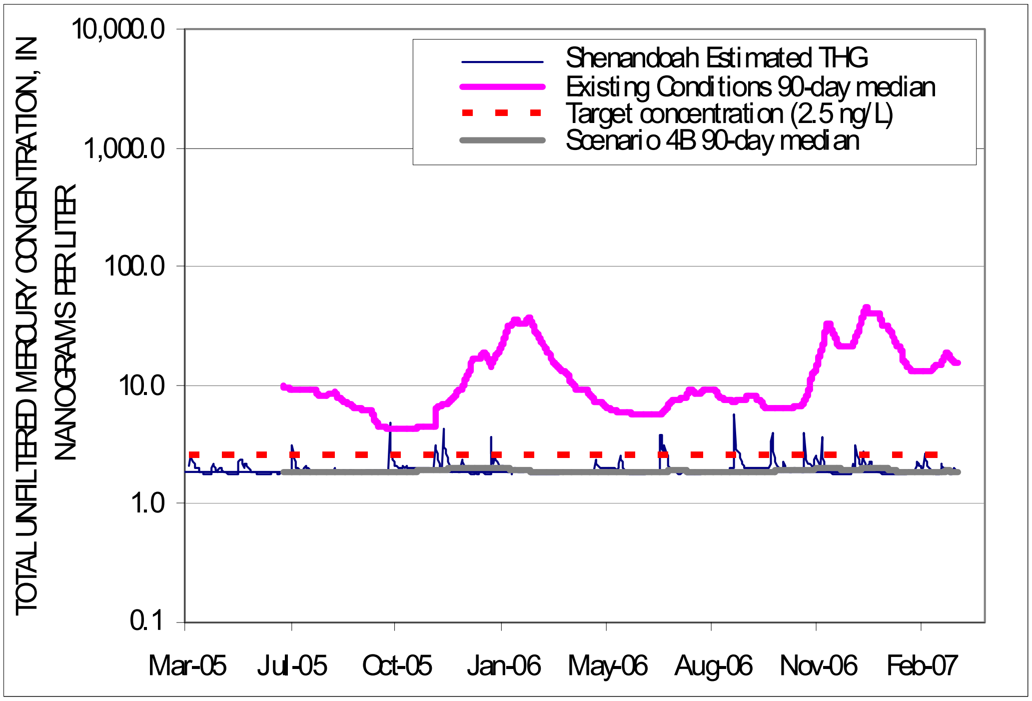


Figure 4-6. Existing Condition and TMDL Scenario for Shenandoah River.

Table 4-7. Total Maximum Daily Load of Mercury for the South Fork Shenandoah River and Shenandoah River Expressed as an Average Annual Load.

Stream	WLA (g/yr)	LA (g/yr)	MOS	TMDL (g/yr)
South Fork Shenandoah River	112*	4008	Implicit	4120
Shenandoah River (at Craigs Run)	112*	5948	Implicit	6060

* - This Wasteload Allocation originates with the identified South River point sources in Table 4-3 and does not allow for additional discharge to downstream segments.

Table 4-8. Total Maximum Daily Load of Mercury for the South Fork Shenandoah River and Shenandoah River Expressed as an Average Daily Load.

Stream	WLA (g/d)	LA (g/d)	MOS	TMDL (g/d)
South Fork Shenandoah River	0.306*	10.982	Implicit	11.288
Shenandoah River (at Craigs Run)	0.306*	16.297	Implicit	16.603

* - This Wasteload Allocation originates with the identified South River point sources in Table 4-3 and does not allow for additional discharge to downstream segments.

Table 4-9. Total Maximum Daily Load of Mercury for the South Fork Shenandoah River and Shenandoah River Expressed as a Maximum Daily Load.

Stream	WLA (g/d)	LA (g/d)	MOS	TMDL (g/d)
South Fork Shenandoah River	0.69*	41.39	Implicit	42.08
Shenandoah River (at Craigs Run)	0.69*	57.21	Implicit	57.90

* - This Wasteload Allocation originates with the identified South River point sources in Table 4-3 and does not allow for additional discharge to downstream segments.

5. TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

Once a TMDL has been approved by USEPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

5.1. CONTINUING PLANNING PROCESS AND WATER QUALITY MANAGEMENT PLANNING

As part of the Continuing Planning Process, VADEQ staff will present both USEPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case of bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in VADEQ's public participation guidelines (VADEQ, 2004), which can be found on VADEQ's web site at: http://www.deq.state.va.us/tmdl/pdf/ppp.pdf.

5.2. ADAPTIVE IMPLEMENTATION STRATEGY

VADEQ intends to implement this TMDL using an adaptive implementation strategy. Adaptive implementation is an iterative implementation process that makes progress toward achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities (Wong, 2006). This approach is particularly useful for the South River mercury TMDL because of the complexities and uncertainties involved in understanding mercury cycling in the South River system. An adaptive implementation strategy allows responsiveness to new information and understanding, and it provides for needed flexibility in implementing the TMDL.

5.2.1. Responsiveness to New Information and Understanding

In 2000, the South River Science Team (SRST) was formed to address technical and scientific aspects of mercury behavior in the South River. The SRST consists of various partners including DuPont and DuPont contractors, VADEQ, Virginia Department of Game and Inland Fisheries, VDH, USEPA, U.S. Fish and Wildlife Service, local environmental groups, and numerous universities and research organizations. Throughout the years, SRST members have conducted numerous studies that have added to the growing understanding of mercury in the South River system. As new information and understanding continue to be developed, implementation efforts should be adaptable enough to take advantage of those advances.

While adaptive implementation is not anticipated to lead to perpetual re-opening of the TMDL, the TMDL and allocation scenarios can be modified in the future if warranted by significant new data or information. The TMDL, as developed, provides the best estimate of necessary mercury source reductions, based on the current understanding of mercury in the South River. If that understanding significantly changes in the future, TMDL modifications may be warranted. Two areas of particular research need are listed below.

- Channel margin sources – The largest source of mercury loading under existing condition simulations was attributed to the channel margins. Parallel loading studies conducted by SRST members have come to similar conclusions, however, these channel margin sources are not well-defined or delineated. Future studies of channel margin sources will be important in advancing the understanding of mercury loading in the South River.

- Mercury methylation and trophic transfer – The empirical bioaccumulation model used in this TMDL to establish protective instream water column concentrations of mercury is based on the current observed relationships between mercury in the water column and methylmercury in fish. Embedded within this empirical relationship are the complex processes of mercury methylation and trophic transfer. If these processes are altered in the system, which is a potential implementation strategy, the empirical relationship and resulting protective instream concentrations would also change. These changes could have a large impact on necessary mercury source reductions. Improved understanding of these processes could also lead to more explicit inclusion of them in South River modeling efforts.

Significant developments that fundamentally change our understanding of the above two areas, for example, may warrant reevaluation of current TMDL assumptions. New data in other less critical areas may not warrant reevaluation of the TMDL, but will still be considered in implementation planning. For example, since the calibration of the South River mercury TMDL model, new data sets of mercury levels in flood plain soils have been developed. These new data provide a much more comprehensive picture of mercury distribution within the flood plain, but do not differ dramatically from TMDL assumptions and do not fundamentally alter our understanding of flood plain mercury. This information, however, may be valuable in evaluating potential remedial options.

5.2.2. Flexibility in Implementing the TMDL

An adaptive implementation approach will allow needed flexibility in exploring, evaluating, and implementing mercury remediation strategies. While the TMDL formally focuses only on mercury source reductions, other avenues of remediation and control will be considered in implementation planning. These options may include treatments or manipulations to reduce bioavailability, interrupt or slow methylation processes, alter trophic transfer, or otherwise cut-off mercury pathways. Implementation of these approaches will require considerable experimentation and pilot testing, but their inclusion in implementation planning will likely be necessary. TMDL modeling shows that complete reliance on mercury source reductions alone will mean meeting extremely large and difficult to achieve reduction levels (99%). A successful implementation plan will likely employ a combination of mercury source controls as well as innovative approaches that influence mercury pathways.

5.2.3. Measures of Success

The mercury TMDL provides a framework for estimating the magnitude of mercury source reductions necessary to restore fish consumption uses. While implementation planning will target those reduction levels, the success of the TMDL will not be measured in mercury loading reductions. The ultimate measure of implementation success will be the resulting methylmercury concentrations in fish from the South River, South Fork Shenandoah River, and Shenandoah River. Any remedial strategies that can impact fish methylmercury levels may be considered in implementation planning.

5.3. IMPLEMENTATION OF WASTE LOAD ALLOCATIONS

To implement the WLA component of the TMDL, Virginia utilizes the National Pollutant Discharge Elimination System (NPDES) program administered by the Commonwealth under authority delegated by the USEPA. Federal regulations require that all new or revised NPDES permits be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). These regulations allow permits to use best management practices (BMPs) in lieu of numeric effluent limitations under certain conditions (40 CFR 122.44(k)). These conditions include where "[n]umeric effluent limitations are infeasible; or [t]he practices are reasonably necessary to achieve effluent limitations and standards or to carry out the purposes and intent of the CWA."

The Commonwealth of Virginia intends to use non-numeric permit requirements to comply with the WLA provisions of the TMDL. In this case, BMPs have been determined to be appropriate and reasonably necessary to achieve water quality standards and to carry out the goals of the TMDL. This approach will entail additional data collection from those facilities assigned a WLA in the TMDL. The additional data collection will better characterize the magnitude and variability of mercury dischargers. Where warranted, BMPs will be implemented through the development and execution of a Pollutant Minimization Plan. Associated BMPs are intended to focus on mercury source tracking and eliminating mercury at its source, rather than end-of-pipe controls; however treatment approaches may be applicable in certain circumstances.

Following USEPA approval of the South River mercury TMDL, VADEQ will reevaluate the permits for facilities with assigned mercury WLAs for inclusion of additional requirements that will ensure compliance with the established WLAs. Reopened or reissued permits should include the following provisions:

- Additional monitoring of mercury using low-level detection techniques (Method 1631) should be conducted. The frequency of testing, quality control requirements, and specific sampling conditions (such as flow) should be prescribed in the permit.

- If the results of monitoring indicate actual or potential exceedance of the protective instream water quality target (3.8 ng/L) or the wasteload allocation specified in the approved TMDL, the permittee would be required to submit for review and approval a Pollutant Minimization Plan (PMP). The plan would be designed to locate and reduce mercury sources to the discharge. The permittee would be required to execute and periodically update the plan until monitoring and/or compliance with approved BMPs demonstrate that the assigned wasteload allocation is consistently met.

Regulatory compliance with the mercury provisions given above would not be based on meeting a specific numeric limit. Through implementing the above provisions, however, there is the expectation that discharged mercury loads would decrease and ultimately meet the assigned numeric wasteload allocations. Regulatory compliance with the mercury provisions of the TMDL would be based on successfully fulfilling the relevant permit requirements, including additional monitoring and development and execution of a PMP, if necessary.

5.4. IMPLEMENTATION OF LOAD ALLOCATIONS

The TMDL program does not impart new implementation authorities. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. In general, implementation measures for point sources are established through the NPDES permit program. Measures for nonpoint source reductions are implemented in an iterative process that is described in the TMDL implementation plan.

5.4.1. Implementation Plan Development

For the implementation of the TMDL’s LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19.7. Virginia’s 1997 Water Quality Monitoring, Information and Restoration Act (the “Act”) directs the SWCB to “develop and implement a plan to achieve fully supporting status for impaired waters". The Act also establishes that the implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments". USEPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process" (USEPA, 1999). The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

In order to qualify for other funding sources, such as USEPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 (VADCR, 2003) and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf. This guidance was not designed specifically for the implementation of mercury TMDLs, but it can provide a useful framework for developing the plan.

The difficulties and complexities of implementing a mercury TMDL will necessitate additional flexibility in the implementation planning. As described above (Section 5.2.2), mercury source reductions alone will likely not be sufficient to cost-effectively restore the fish consumption use. Additional innovative strategies that reduce bioavailability, interrupt or slow methylation processes, alter trophic transfer, or otherwise cut-off mercury pathways will likely be needed and will be considered throughout implementation plan development. Since these innovative approaches are not well established, the initial stages of TMDL implementation may include additional data collection, research, and testing. In fact, some of these tasks have already begun. With the support of the SRST, DuPont has formed a Remedial Options Team and initiated a Remedial Options Program. This team has begun and will continue to investigate traditional, as well as, innovative remediation techniques. A pilot bank stabilization project initiated by the team is currently underway. VADEQ anticipates that a successful implementation plan will likely contain a combination of treatment technologies, source removal, source controls, BMPs, administrative controls, and innovative strategies that interrupt mercury pathways.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, the Virginia Department of Game and Inland Fisheries, other cooperating agencies, and the SRST will provide technical resources to assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

5.4.2. Link to Ongoing Restoration Efforts

Other ongoing water (and air) quality improvement efforts will contribute to the implementation of this mercury TMDL. A summary of those efforts are provided below:

- Virginia's Water Clean-up Plan – In 2006, the Virginia General Assembly passed legislation requiring the Secretary of Natural Resources to develop a plan for the clean up of the Chesapeake Bay and Virginia's waters (HB 1150). This plan (Commonwealth of Virginia, 2007) addresses both point and nonpoint sources of pollution and includes measureable and attainable objectives for water clean up, attainable strategies, a specified timeline, funding sources, and mitigation strategies. Additionally, challenges to meeting the clean-up plan goals (i.e., lack of program funding, staffing needs, monitoring needs) are identified. Information regarding Virginia's Water Clean-up Plan can be found at http://www.naturalresources.virginia.gov/Initiatives/WaterClean-upPlan/.

- Chesapeake Bay Nutrient and Sediment Tributary Strategy – In 2005, the Secretary of Natural Resources developed tributary strategies for the major basins discharging to the Chesapeake Bay (VASNR, 2005). These strategies set nutrient and sediment reductions for the basins and highlight practices to achieve those reductions. Many of the BMPs that will be used to reduce nutrients and sediment contributions as part of the Potomac River Basin Tributary Strategy will also reduce mercury loads to the South River. Since the majority of mercury entering the river is attached to sediments, reductions in sediment from the contaminated flood plain will also reduce mercury loadings. More information on the Potomac Basin Tributary Strategy can be found at: http://www.naturalresources.virginia.gov/Initiatives/WaterQuality/FinalizedTribStrats/shenandoah.pdf.

- Air Quality Regulations – The USEPA promulgated the Clean Air Interstate Rule (CAIR) in 2005. This legislation will reduce emissions of air pollutants, including mercury, by 2015. In addition, the Clean Air Mercury Rule (CAMR) was promulgated to specifically cap and reduce mercury emissions. These rules are estimated to result in a 19% reduction in mercury deposition within the South River watershed. While the overall contribution of atmospheric mercury to the South River impairment is small, the anticipated 19% reduction is included in the TMDL scenario.

- Natural Resources Defense Council (NRDC)/Sierra Club Settlement Agreement – In 2005, DuPont entered into a settlement agreement and a resulting consent decree with the NRDC and Sierra Club. This agreement committed DuPont to a six-year study of mercury in the South River ecosystem. Phase I of the study has been completed and has generated valuable information characterizing the extent of mercury contamination. Phase II will focus on specific sources of mercury and mercury methylation sites. Following the completion of the study, the parties will negotiate remedial options.

- Natural Resource Damage Assessment (NRDA) Process – The U.S. Fish and Wildlife Service has initiated a Natural Resource Damage Assessment (NRDA) on the South River. The NRDA program is designed to identify the natural resources injured by contamination, recover damages from responsible parties, and plan and carry out restoration activities. This process is currently in the damage assessment phase in the South River, but ultimately there is an expectation of restoration activities in the watershed.

- Resource Conservation and Recovery Act (RCRA) Clean up – Under USEPA oversight, DuPont is currently conducting a RCRA facility investigation at the former DuPont plant site. This activity has involved groundwater, stormwater, and soil testing on the plant site. Soon, corrective action measures will be taken to address solid waste management units that pose a human health or ecological risk.

- TMDLs for Other Pollutants – In addition to the mercury TMDL, TMDLs are also being developed for bacteria, sediment, and phosphorus in the South River. Implementation plans that specifically address these pollutants will also be required. In many cases, elements of these plans may assist in reducing mercury inputs. For example, best management practices to reduce sediment loading in flood plain areas will also reduce the loading of mercury attached to those sediments. Exclusion of livestock from the river to reduce bacteria loading will also reduce trampling of the banks and channel margin sources of mercury. Reductions in nutrient loadings may decrease microbial activity and subsequently reduce mercury methylation. Some studies, however, have shown increases in mercury bioaccumulation when nutrient levels are reduced, such that the net impact of nutrient reductions on fish tissue levels may not be predictable. Continued monitoring will need to evaluate mercury conditions as other TMDLs are implemented.

5.4.3. Implementation Funding Sources

The implementation of pollutant reductions from nonpoint sources typically relies heavily on incentive-based programs. Therefore, the identification of funding sources for nonpoint source implementation activities is a key to success. Typical sources for implementation funding include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, USEPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions. These traditional sources of funding may play a limited role in the implementation of the mercury TMDL. Their role will likely be in funding implementation of TMDLs for bacteria, sediment, and phosphorus in the South River, which will provide ancillary mercury reductions. Other state sources of funding, such as the Virginia Environmental Emergency Response Fund (VEERF), could also apply to mercury clean up in the South River.

Because the mercury impairment on the South River resulted from legacy contamination at the former DuPont site, DuPont retains some obligations with respect to funding clean up. These obligations include existing and potential settlement agreements, RCRA corrective actions, and

NRDA restoration activities. While the details of remediation activities or funding levels have not yet been established within any of these programs, DuPont has committed to engaging in each process.

5.5. FOLLOW-UP MONITORING

Following the development of the TMDL, VADEQ will continue to monitor methylmercury levels in fish from the impaired rivers through the Fish Tissue and Sediment Monitoring Program. This program monitors the levels of organic and inorganic contaminants (including mercury) in fish and sediment across the Commonwealth. From year to year, routine monitoring rotates among the major river basins in Virginia.

In addition to routine fish and sediment monitoring, VADEQ has instituted a 100-yr monitoring program for mercury in the South River and South Fork Shenandoah River. As a result of a 1984 settlement agreement between DuPont and the SWCB, DuPont established a trust fund to implement this 100-yr monitoring effort. The monitoring schedule includes periodic monitoring of mercury in fish, sediment, water, and flood plain soils throughout 2092. Lastly, SRST members continue to conduct ongoing monitoring of mercury in the South River system, including water, sediment, soils, invertebrates, fish, reptiles, birds, and mammals. SRST members have suggested yearly monitoring of young-of-the-year fish in order to more dynamically track ongoing trends and progress during implementation. This suggestion has value and should be considered during Implementation Plan development.

VADEQ staff, in cooperation with VDH and the SRST, will continue to use data from the various monitoring programs to evaluate the accuracy of fish consumption advisories, reductions in pollutants (“water quality milestones” as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts.

5.6. ATTAINABILITY OF DESIGNATED USES

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of the Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevents the attainment of the use;
2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;
5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or
6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the USEPA, will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/.

The process to address potentially unattainable reductions based on the above is as follows: As a first step, measures targeted at the controllable, anthropogenic sources identified in the TMDL's staged implementation scenarios will be implemented. The expectation would be for the reductions of all controllable sources to the maximum extent practicable using the implementation approaches described above. VADEQ will continue to monitor biological health and water quality in the stream during and subsequent to the implementation of these measures to determine if water quality standards are attained. This effort will also help to evaluate if the modeling assumptions were correct. In the best-case scenario, water quality goals will be met and the stream's uses fully restored using effluent controls and BMPs. If, however, water quality standards are not being met, and no additional effluent controls and BMPs can be identified, a UAA would then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E provides an opportunity for aggrieved parties in the TMDL process to present to the SWCB reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The Board may then allow the aggrieved party to conduct a UAA according to the criteria listed above and a schedule established by the Board. The amendment further states that "If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed."

6. PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive input from stakeholders and to apprise the stakeholders of the progress made. Public participation was encouraged through holding public meetings in the watershed and by forming a Technical Advisory Committee (TAC). The TAC generally consisted of a subset of SRST members that provided input and assistance to VADEQ during the TMDL development. The goal of the TAC was to make sure that the technical aspects of the study (including model inputs and assumptions) were accurate as well as acceptable to the stakeholders.

On July 17, 2006, VADEQ held a public meeting at the Waynesboro Municipal Building to explain the South River mercury impairment to local citizens and describe the TMDL development process. The meeting was advertised through signs and posters throughout the watershed, e-mail announcements, letters to VPDES permit holders, notice publication in the Virginia Register, and press releases to the local media. Approximately 18 people attended the meeting. At the meeting, VADEQ explained the mercury impairment in the South River, described the TMDL process, and provided an open invitation to participate on the TAC. Handouts of the presentation were made available to attendees of the meeting and were distributed electronically upon request to those that were not able to attend the meeting.

The TAC met on seven occasions to discuss progress on the mercury TMDL. The TAC met once prior to the first public meeting on February 7, 2005, and then quarterly from October 2007 through January 2009. At each meeting, the TAC was updated on the status of the TMDL and asked to provide input on the model development. Prior to a final public meeting, the TAC was provided a preliminary draft of the TMDL report for comment and input.

On June 11, 2009, a second public meeting was held in the South River watershed. This meeting was once again advertised through e-mail announcements, notice publication in the Virginia Register, and through press releases to the local media. Approximately 20 people attended this final public meeting. At the meeting, VADEQ presented the draft TMDL report to the public and explained its development and conclusions. An executive summary of the draft report was made available to the public at the meeting. The full report was made available on the VADEQ website at: https://www.deq.virginia.gov/TMDLDataSearch/DraftReports.jspx. Following the meeting, a 30-day public comment period on the draft was initiated. Four sets of comments were received on the draft during the public comment period. VADEQ responded to all comments received and revised the draft report accordingly.

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ATTACHMENT 1:

Eggleston, J. 2009. *Mercury Fluxes in the South River of the Shenandoah Valley of Virginia and Development of Mercury Total Maximum Daily Loads (TMDLs) for the South River, South Fork Shenandoah River, and Shenandoah River*. U.S. Geological Survey Scientific Investigations Report 2008-XXX, XXX p.